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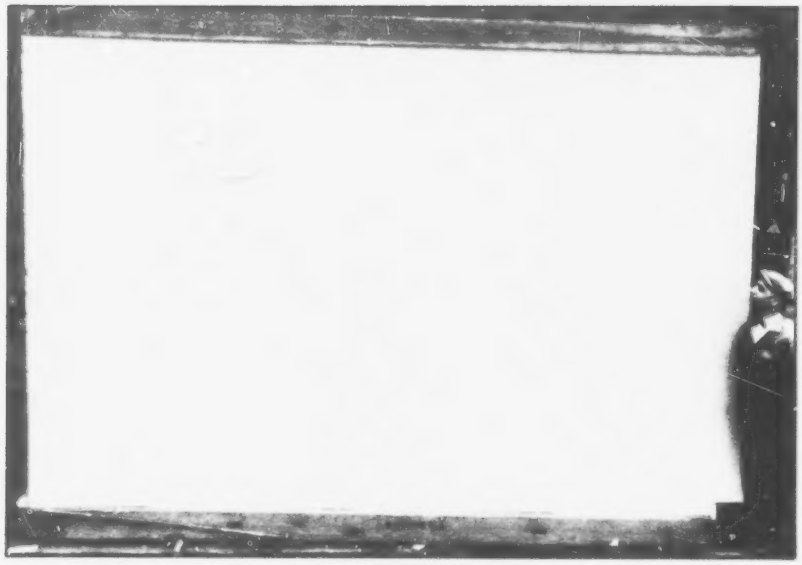
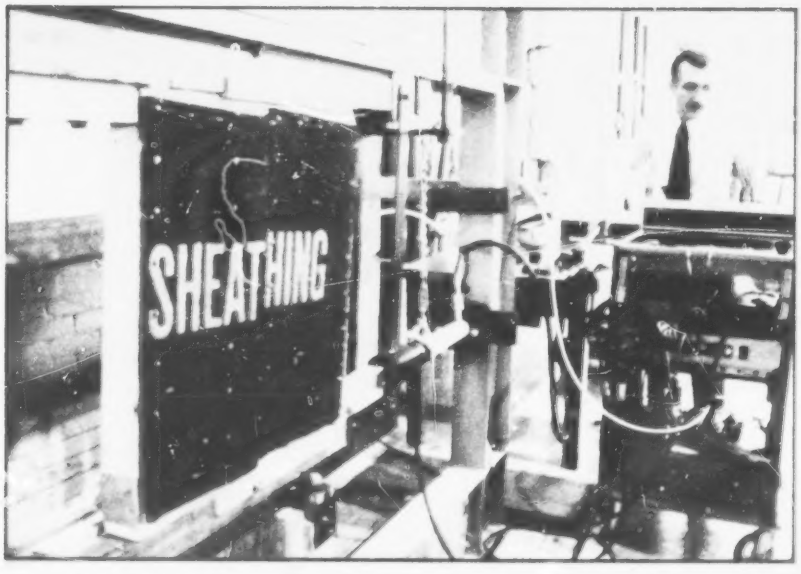
Fiberboard and Hardboard Research at the Forest Products Laboratory

A 50-Year Summary





Abstract

Many changes have occurred in the fiber-based panel products industries during the past 50 years. During this timespan the Forest Products Laboratory has conducted a considerable amount of research on processing and product evaluation of fiber-based panel product materials. Unfortunately about 26 percent of this information was never published.

This report compiles all of the studies completed during this timespan and briefly summarizes what was accomplished.

Keywords: Hardboard, fiberboard, summary, processing, raw materials, properties, performance.

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On the Cover

Top. Racking test of full-scale (9-by 14-ft) wall section with fiberboard sheathing conducted at FPL in 1932.
Bottom. Small-scale (2-by 2-ft) wall racking test developed at FPL in 1976 as an economical way to augment full-scale testing.

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Fiberboard and Hardboard Research at the Forest Products Laboratory
A 50-Year Summary

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Introduction

The Forest Products Laboratory, U.S. Department of Agriculture, Forest Service, has been conducting research on fiber-based panel products since the early 1930's (Luxford 1932), and was probably the only public institution actively engaged in systematic wood research during the 1930's and early 1940's. This report is a compilation of all the studies completed at the Laboratory and a summary of what was accomplished. About 26 percent of the references and findings were never published, but are on file at the Laboratory. These findings were not made public because the scientist did not think existent information justified publication or because the information was presented in a letter or report to another agency or to industry as part of a cooperative venture.

In addition to the experimental research reported here, FPL has also produced information (FPL resource bulletins) on hardboard and fiberboard raw material requirements, production, and uses (Dickerhoof 1978a, 1978b; Dickerhoof and McKeever 1979; McKeever 1979).

Different terms have been used to identify the various panel products made from wood fibers and intended primarily for building construction and furniture and cabinet manufacture. The Wood Handbook (Forest Products Laboratory 1974) refers to them as "building fiberboards." The American Society for Testing and Materials definitions (ASTM 1978a) refer to them as "fibrous-felted boards," divided further into "structural insulating boards" (less than 31 pounds per cubic foot (lb/ft^3)) and "hardboards" (greater than 31 lb/ft^3). In this paper "cellulosic fiberboard" means wood-fiber panels of 10 to 31 lb/ft^3.

Cellulosic fiberboard, the oldest of the fiber-base panels, was developed in 1914. The production of cellulosic fiberboard has peaked and is now declining. A process for manufacturing a hard-pressed fiberboard (hardboard) was developed in 1926. Hardboard production has been increasing, with some of the biggest gains occurring in hardboard siding. High-density hardboard is also starting to find uses as a structural material (McNatt 1980).

A more recent development is medium-density fiberboard (MDF), which combines the technologies of the hardboard and particleboard industries. There was much debate over the definition of MDF until the American Hardboard Association and the National Particleboard Association jointly sponsored an American National Standards Institute standard for MDF (ANSI 1980). Medium-density fiberboard is manufactured from wood fibers combined with a synthetic resin, usually urea formaldehyde, and is intended for interior use. It has been replacing other panel products in the furniture industry, and has experienced phenomenal growth in the United States and worldwide.

Manufacturing and Raw Material Variables

Fiber Resources

Fiber can be obtained from a multitude of sources besides the traditional pulpwood. One good source is waste from other primary forest products processes, including sawmill wastes (Schwartz and others 1947a, 1947b, 1950a; Turner and Kern 1956; Forest Products Laboratory 1950), logging wastes (Schwartz and others 1947b), chipper rejects and various pulpmill wastes (Forest Products Laboratory 1950), and veneer scrap (Schwartz 1951c). Schwartz and Baird (1952) made an early attempt to use branchwood only as a fiber source, and more recently Steinmetz and Fahey (1979) described the use for this purpose of whole tree material, which is the entire aboveground portion of the tree. Laundrie and McNatt (1975) investigated urban forest as a source of diseased trees for use in hardboard. They also considered industrial discards of used pallets, and wood from old railroad cars, while Steinmetz (1974) considered waxed corrugated as a source of fiber. Both Laundrie and McNatt (1975) and Schwartz (1951a) investigated municipal solid wastes which contain large quantities of wastepapers. Laundrie and McNatt (1975) also investigated the much cleaner and more uniform household wastepaper and newsprint, and Schwartz (1951a) investigated some rather unusual waste products from processing agricultural commodities. These included peanut hulls, chicken feathers, leather scraps, and fibrous material from cattle stomachs.

Many species of trees have been investigated to determine if they are suitable for manufacturing hardboards. These include many domestic hardwoods, domestic softwoods, and some foreign woods (table 1). Nelson (1973) examined wood specific gravity and fiber length of eight species (table 2) in greater detail to determine their influence on medium-density hardboard performance (table 3).

Regardless of the source, many chips become moldy or begin to decay during storage in large piles. The effect of this deterioration on hardboards made from chips was investigated by Myers (1983), Razzaque (1962), Schwartz and Chaline (1950b). Generally, they found a strength reduction and or an increase in linear movement.

Fiber Preparation

Before it is possible to make any type of fiberboard, it is necessary to break down the raw material into individual fibers or fiber bundles. These are generally lignocellulose fibers obtained from some form of wood chip. Several means of reducing wood chips to fibers have been examined in the past, when limitations of laboratory equipment largely controlled the type of study conducted. The Laboratory possessed an assortment of chemical pulp digesters, various sizes and types of atmospheric pulp refiners, and a small laboratory-size Asplund Defibrator. Nearly all of the studies on fiber preparation that were completed were part of other, perhaps larger, studies. Few, if any, had fiber preparation as a primary objective.

In a few studies (Razzaque 1962; Schwartz et al. 1947b, 1950b) mild chemical cooks, followed by refining or mechanical agitation, were used to prepare fibers for board manufacture. In one study (Turner and others 1948) raw wood chips were passed through an atmospheric attrition mill in an attempt to obtain fibers for board manufacture. By far the majority of the investigations concerned either steam-cooking at diverse temperatures and times followed by some form of atmospheric attrition milling (McGovern and others 1949; Schwartz 1951c; Schwartz and others 1947b, 1950b, 1952), or investigating different pressures and other operating parameters of the laboratory-size Asplund Defibrator (Razzaque 1962; Schwartz 1958a; Schwartz and Baird 1952; Steinmetz 1968). Two studies (Schwartz 1963b, Schwartz and Baird 1950a) measured the amount of power consumed during the refining of hardboard furnish in laboratory-size attrition mills. Schwartz (1958b) and Steinmetz (1973) investigated effects of the type and severity of the fiber preparation procedures on yield of fiber (table 4). Schwartz (1958b) showed also how the fiber yield influences wet-forming characteristics and board performance (table 5). Steinmetz (1973) made some attempt to remove extractives with hot water and dilute caustic washes to improve the suitability of some wood species for hardboard manufacture (fig. 1).

Several fiber characteristics can ultimately affect board performance. Several studies (Nelson 1973, Schwartz and Baird 1950a, Steinmetz and Fahey 1971, Turner and Kern 1956) have shown how the different screen fractions can affect drainage rate on the machine as well as appearance and performance of the board. Hrubesky (1949) and Hrubesky and Perot (1954) showed drainage rate is sensitive to other variables also. Nelson (1973) showed that the amount of lignin originally present in the fiber and the amount remaining after preparation can also affect board performance; he demonstrated the great importance of pH as a fiber characteristic, because it can affect the resin cure and ultimately board performance. Myers (1977, 1978), however, showed that to a certain extent the negative effects of low fiber pH can be overcome.

Table 1.—Species evaluated for hardboard and insulation board

Common name	Botanical name	Reference
DOMESTIC HARDWOODS		
ash	--	Schwartz 1951b
aspen	*Populus tremuloides*	Schwartz and Heinig 1947a, Steinmetz 1968, Steinmetz and Fahey 1979, USDA Forest Service 1950
basswood	*Tilia americana* L.	Schwartz 1951b
boxelder	*Acer negundo* L.	Nelson 1973
beech	*Fagus grandifolia* Ehrh.	Schwartz 1960b
elm	*Ulmus americana* L.	Laundrie and McNatt 1975, Schwartz 1951b
red alder	*Alnus rubra* Bong.	Schwartz 1958b
red oak	*Quercus rubra* L.	Lewis and Heebink 1971; Myers 1977, 1978; Steinmetz 1973
sand hickory	*Carya pallida* (Ashe) Engl. and Graebn.	Schwartz and Baird 1952
soft maple	--	Schwartz 1951b
southern oaks (3 red and 3 white)	--	Lewis and Heebink 1971, Schwartz 1958b
sugar maple	*Acer saccharum* Marsh.	Schwartz 1951b, 1955, 1960b
sweetgum	*Liquidambar styraciflua* L.	Rosenfeld 1959
sycamore	*Plantanus occidentalis* L.	Laundrie and Fahey 1973
white birch	*Betula papyrifera* Marsh.	Schwartz 1960b
white oak	*Quercus alba* L.	Lewis and Heebink 1971; Nelson 1973; Schwartz 1953b, 1963a, 1963b
DOMESTIC SOFTWOODS		
Alaska cedar	*Chamaecyparis nootkatensis* (D. Don.) Spach	Nelson 1973
balsam fir	*Abies balsamea* (L.) Mill.	Myers 1977, 1978; Nelson 1973; Schwartz 1963b
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco	Nelson 1973; Schwartz 1958a, 1963a; Schwartz and Baird 1950a, 1950b
Engelmann spruce	*Picea engelmannii* Parry	Schwartz 1958a
hemlock	*Tsuga canadensis* (L.) Carr.	Schwartz 1951b
loblolly pine	*Pinus taeda* L.	Steinmetz and Fahey 1979
lodgepole pine	*Pinus contorta* Dougl.	Schwartz 1958a
northern white cedar	*Thuja occidentalis* L.	Nelson 1973
Sitka spruce	*Picea sitchensis* (Bong.) Carr.	Nelson 1973
slash pine	*Pinus elliotti* (Engelm.)	Nelson 1973
FOREIGN WOODS		
caracoli	*Anacardium excelsum*	Schwartz and Baird 1948
chestnut	*Castanea sativa*	Schwartz 1949
eucalyptus	*Eucalyptus rostrata*	Schwartz 1951c
European beech	*Fagus sylvatica*	Schwartz 1949, Schwartz and Chaline 1950b
jobo	*Spondias mombin*	Schwartz and Baird 1948
mixed tropical hardwoods (50 species)	--	Myers 1979
ohia	--	Schwartz 1960a
okume	*Aucoumea klaineana*	Schwartz 1951c
orange wood	--	Schwartz 1953a
sundri	*Heritiera minor*	Razzaque 1962

Table 2.—Wood specific gravity and fiber length (Nelson 1973)

Factorial class		Species	Specific gravity[1]	Fiber length[1]
Specific gravity	Fiber length			
				mm
Low	Short	Alaska cedar	0.406 (0.403-0.408)	2.65 (2.58-2.72)
		Northern white-cedar	.260 (.253- .268)	2.77 (2.74-2.80)
		Average	.333	2.71
Low	Long	Sitka spruce	.352 (.340- .365)	3.81 (3.80-3.82)
		Balsam fir	.332 (.332- .332)	3.16 (3.04-3.28)
		Average	.342	3.48
High	Short	White oak	.620 (.607- .634)	1.14 (1.08-1.21)
		Boxelder	.452 (.440- .464)	0.66 (0.64-0.68)
		Average	.536	0.90
High	Long	Douglas-fir	.448 (.446- .451)	3.20 (3.17-3.23)
		Slash pine	.568 (.545- .592)	4.43 (4.27-4.59)
		Average	.508	3.82
Low			.338	--
High			.522	--
	Short		--	1.80
	Long		--	3.65

[1] Numbers in parentheses are values for two replicates (range for species); other values are means.

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Table 3.—Analysis of variance (ANOVA)—hardboard strength properties, dimensional stability, and water absorption (Nelson 1973)

Hardboard property		Significance of F value Source of variation (effect)			
		Specific gravity (wood)	Fiber length (wood)	Specific gravity x fiber length (wood)	Species within factorial cells
Modulus of rupture		*[1]	NS[2]	NS	**[3]
Modulus of elasticity		*	*	NS	**
Tensile strength		NS	*	NS	**
Compressive strength		NS	NS	NS	NS
Internal bond		NS	NS	NS	*
Length change from 50 pct RH[4] to:					
	Ovendry	NS	*	NS	NS
	90 pct RH	NS	**	NS	**
	Water-soaked condition	*	**	NS	**
Thickness change from 50 pct RH to:					
	Ovendry	NS	*	NS	NS
	90 pct RH	NS	**	NS	**
	Water-soaked condition	*	**	NS	*
Weight (moisture) change from 50 pct RH to:					
	Ovendry	NS	NS	*	NS
	90 pct RH	NS	*	NS	**
	Water-soaked condition	NS	NS	NS	NS

[1] Significant at 0.05 level of probability.

[2] Not significant at 0.05 level of probability.

[3] Significant at 0.01 level of probability.

[4] RH, relative humidity.

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Table 4.—Processing conditions and yields of pulp for red alder and mixture of oak fiberized in a laboratory-model Asplund defibrator (Schwartz 1958b)

Species	Defibrator run number	Processing conditions				Pulp		
		Steam pressure	Presteaming period	Milling period	Total time	Number or runs	Yield	Asplund freeness
		Lb in.^{2}	Min				Pct	s
Red alder	88	175	1	1	2	4	95.2	14
	93	175	1	3-1/2	4-1/2	4	84.8	16
	92	175	1	6	7	8	80.0	18
Mixture of oaks	97	125	1	1	2	4	91.5	12
	98	125	1	3-1/2	4-1/2	4	83.2	18
	99	125	1	6	7	4	78.7	22

Table 5.--Properties of hardboards made from red alder and from a mixture of southern oaks (Schwartz 1958b)

Yield	Molding press	Size	Alum	Defibrator freeness	Specific gravity	Modulus of rupture	Toughness	Water absorption	Thickness change
Pct	Lb in.^{2}	Pct		s		Lb in.^{2}	In.lb per in. of width	Pct	
RED ALDER									
95.2	500	0	1	40	.98	7,350	11.0	60.0	36.0
95.2	500	1	1	40	.98	5,100	8.0	28.3	20.6
84.8	500	0	1	43	1.04	8,460	12.8	49.0	29.4
84.8	500	1	1	41	1.03	6,340	9.7	2[illegible].5	19.2
80.0	500	0	1	43	1.08	8,330	10.0	42.4	25.6
80.0	500	1	1	42	1.05	[1]5,210	9.4	18.0	14.7
OAK MIXTURE									
91.5	500	0	8	38	.98	6,330	6.6	49.5	26.1
91.5	500	1	8	39	1.01	5,100	5.0	18.9	18.9
83.2	500	0	8	42	1.04	7,480	7.5	40.9	23.4
83.2	500	1	8	44	1.03	5,750	6.3	18.9	15.6
78.7	500	0	8	41	1.06	6,380	4.0	27.8	14.4
78.7	500	1/2	6	43	1.05	5,720	4.4	18.7	12.8

[1] This value is low. The variability of the results obtained is reflected by this value, which is in variance with the overall data.

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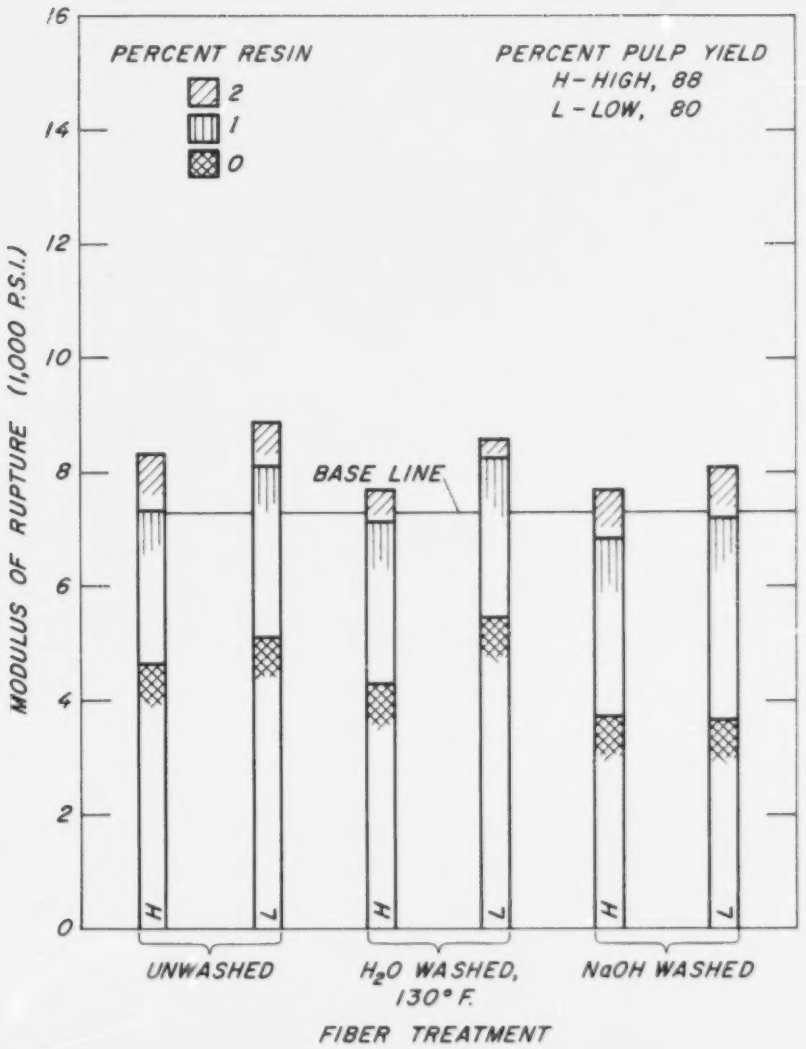

Figure 1.—Relationship of modulus of rupture to fiber treatment of wet-formed red oak hardboards. Steinmetz 1973. (M141 229)

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Additives and Fiber Treatments

Sizing Materials

Some form of sizing material is added to the fibers in the manufacture of all wet-formed, and most dry-formed hardboard. Some of these materials impart moisture resistance or help affix other additives to the fiber in wet-forming. Petroleum wax (paraffin-like material) is usually added to both wet- and dry-formed hardboard to impart more moisture resistance (Egerstrand and Schwartz 1950). Aluminum sulfate and sulfuric acid are routinely added to wet-formed hardboard to affix an emulsified paraffin-like material and phenolic resin to the fiber, so they remain when the water is drained away (Schwartz and Chaline 1950b). Egerstrand and Schwartz (1950) attempted to substitute aluminum stearate and ferric stearate for aluminum sulfate or ferric sulfate. These materials gave as good water resistance as paraffin wax, but they reduced flexural strength.

Schwartz and Chaline (1950a) showed that the presence or absence of a sizing material, when coupled with pressing temperatures, made a difference in board performance (table 6). Schwartz (1953b, 1958a) showed that the type and amount of sizing used definitely influenced board properties (table 7), usually increasing water resistance but reducing modulus of rupture, and specific sizing requirements had to be adjusted for each fiber. Schwartz (1958b) found that increasing the aluminum sulfate content above 2 percent generally decreased all strength properties, but this is dependent on fiber yield.

Resins

Phenol-formaldehyde resins are usually added to high- and medium-density hardboards to improve their strength and dimensional change properties. Not all phenolic resins are the same, and many are formulated for a specific plant and process. Nearly all of the phenolic resin used in hardboard manufacture is liquid, but Myers (1976) and Steinmetz and Fahey (1968) have made trials in which powdered phenolics have also been used to make hardboards or low-density panel products. Fahey and Pierce (1973) and Steinmetz (1977) investigated the effects of four variables (low- and medium-viscosity, bonding- and impregnating-type resins) on hardboard properties such as strength, dimension change and water adsorption. The lower viscosity and penetrating-type phenolic resins had their greatest effect on dimension and weight change results, whereas the higher viscosity and bonding-type phenolic resins had a greater effect on strength. One would expect the amount of phenolic resin used to affect hardboard properties, and several studies (Myers 1976, Steinmetz 1973, Steinmetz and Fahey 1971) have shown they do so to different extents. Sometimes the addition of a little more resin has been decisive to success in meeting instead of falling below specified strength criteria, improving dimensional stability, or being able to utilize a wood species that might otherwise be considered unacceptable. Because phenolic resins are relatively expensive, hardboard manufacturers try to use as little as possible.

Powdered thermoplastic resins are considerably cheaper than phenolic resins, and several studies have been conducted to utilize them in hardboard manufacturing (Schwartz 1963b, Steinmetz 1977, Steinmetz and Fahey 1971). Generally, considerably more thermoplastic resin has to be used to equal the quality achieved with phenolic resins. Thermoplastic resins can also be combined with phenolic resins, in which case less phenolic resin is used, but the overall resin content must be greater than when phenolic is used alone (Steinmetz and Fahey 1968).

Schwartz and Heinig (1947) processed neutral sulfite semichemical pulp in a beater until it gelatinized, and used it as a binder for insulation board made from sawdust, at a gelatinized pulp binder content of 15 percent. In the same study they looked into the possibility of using an identical binder concentration of repulped, but not gelatinized, old newspapers.

Steinmetz (1977) made an attempt to use a two-part epoxy resin as a binder for hardboard manufacture. Unfortunately the epoxy resin viscosity was so high it could not be sprayed onto the fiber, so no hardboards were manufactured.

Many MDF plants use radiofrequency (RF) waves to hasten the ureaformaldehyde adhesive cure. Unfortunately, MDF made with urea-formaldehyde adhesive can only be used in interior applications. Phenolic adhesive cannot be used with RF curing because it causes arcing and burning problems. By using a phenol-resorcinol adhesive, Fahey (1976) was able to make MDF board in a press with RF curing. The finished board had much better durability than urea-bonded board, and could be used outdoors.

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Table 6.—Hardboards from southern pine, sweetgum, red oak, and cypress sawmill wastes (Schwartz and Chaline 1950a)

Material	Pulp Yield	Stock					Hotpressing conditions			Board properties				
										Specific gravity	Modulus of rupture	Adjusted modulus of rupture[2]	24-hour water immersion test	
		Refined[1]	Rosin size	Alum	pH	Asplund freeness	Maximum pressure	Maximum temperature	Time				Water absorption	Thickness increase
	Pct		------Pct------			s	Lb in.^{2}	C	Min		------Lb in.^{2}------		------Pct------	
Southern pine	85.2	No	0	0	--	13	500	200	10	1.04	4,660	4,300	58.3	36.2
		No	0	0	--	13	500	240	10	1.03	7,380	7,000	41.2	18.8
		Yes	0	0	--	36	500	200	10	1.04	6,040	5,600	55.2	33.6
		Yes	1.5	1.5	4.2	45	500	200	10	1.03	3,740	3,500	25.9	20.6
Unbarked southern pine slabs	83.0	No	0	0	--	21	500	200	10	1.01	4,530	4,400	55.5	30.5
		No	0	0	--	21	500	240	10	1.00	6,830	6,800	34.3	16.1
		Yes	0	0	--	47	500	200	10	1.00	5,180	5,200	57.3	29.3
		Yes	1.5	1.5	4.25	46	500	200	10	1.02	3,460	3,300	23.7	16.4
Sweetgum	86.8	No	0	0	--	18	500	200	10	1.03	7,630	7,200	64.1	44.5
		No	0	0	--	18	500	240	10	1.04	9,060	8,400	45.0	21.1
		Yes	0	0	--	44	500	200	10	1.02	7,980	7,700	60.5	39.7
		Yes	1.5	1.5	4.4	57	500	200	10	.99	5,060	5,200	30.1	23.2
Red oak	82.9	No	0	0	--	29	500	200	10	1.02	6,160	5,900	54.6	34.8
		No	0	0	--	29	500	240	10	1.04	7,720	7,100	34.1	15.1
		Yes	0	0	--	49	500	200	10	1.04	7,260	6,700	53.0	32.6
		Yes	1.5	1.5	4.3	56	500	200	10	1.04	4,630	4,300	25.9	18.9
Cypress	88.8	No	0	0	--	12	500	200	10	.98	4,700	4,900	54.0	31.9
		No	0	0	--	12	500	240	10	1.02	8,350	8,000	34.2	15.4
		Yes	0	0	--	46	500	200	10	.99	5,530	5,600	54.0	28.1
		Yes	1.5	1.5	4.2	61	500	200	10	.98	3,960	4,100	39.1	21.0
Southern pine shavings	81.9	No	0	0	--	15	500	200	10	1.00	3,640	3,600	52.9	33.6
		No	0	0	--	15	500	240	10	1.06	6,280	5,600	28.6	14.5
		Yes	0	0	--	42	500	200	10	.98	4,770	5,000	54.3	31.3
		Yes	1.5	1.5	4.3	59	500	200	10	.98	2,920	3,000	48.9	28.4
40 pct southern pine	85.3	No	0	0	--	17	500	200	10	1.03	6,380	6,000	54.6	34.6
20 pct sweetgum		No	0	0	--	17	500	240	10	1.08	8,950	7,700	34.3	16.9
20 pct red oak		Yes	0	0	--	48	500	200	10	1.00	6,190	6,200	55.5	32.4
20 pct cypress		Yes	1.5	1.5	4.6	80	500	200	10	1.00	3,830	3,800	23.1	16.6
40 pct unbarked southern pine slabs	83.6	No	0	0	--	21	500	200	10	.97	4,330	4,600	58.6	3.53
20 pct unbarked sweetgum pine slabs		No	0	0	--	21	500	240	10	1.03	6,220	5,900	36.9	17.4
20 pct unbarked red oak slabs		Yes	0	0	--	37	500	200	10	1.02	5,240	5,000	54.3	32.9
20 pct unbarked cypress slabs		Yes	1.5	1.5	4.2	56	500	200	10	.94	2,970	3,400	25.5	17.2
Hardwood sawdust mixture	78.7	No	0	0	--	17	500	240	10	.98	2,650	2,800	--	--

[1] Asplund stock refined in an 8-inch single-rotating-disk attrition mill.

[2] Modulus of rupture adjusted to a specific gravity of 1.0 on the basis that the flexural strength varies as the square of the specific gravity.

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Table 7.—Effect of pulp yield, sizing, and molding on white oak hardboard properties (Schwartz 1953b)

Pulp yield	Refined stock	Sizing data[1]				Freeness (defibrator)	Hotpressing conditions[2]		Board data				
		Rosin	Alum	Ferric sulphate	pH		Temperature	Schedule[3]	Specific gravity	Modulus of rupture		Water absorption	Thickness increase[5]
										Original	Adjusted[4]		
Pct		Pct				s	°C	Min		lb/in.^{2}		Pct	
75.3	No	0	0	0	7.6	34	180	2-1-7	1.07	5,700	5,000	50	30
81.7	No	0	0	0	7.7	22	180	2-1-7	1.04	5,700	5,300	67	50
81.7	No[6]	0	0	0	7.5	23	195	2-1-7	1.02	5,550	5,300	57	35
75.3	No	0	0	0	7.2	37	240	1-2-7	1.07	7,530	6,600	28	12
81.7	No	0	0	0	7.7	24	240	1-2-7	1.02	6,640	6,400	31	14
81.7	No[6]	0	0	0	7.5	24	240	1-2-7	1.01	6,140	6,000	30	15
81.7	Yes	0	0	0	7.9	38	240	1-2-7	1.07	8,150	7,100	31	15
75.3	Yes	1.5	1.5	0	4.2	53	180	2-1-7	1.06	4,540	4,000	42	25
75.3	Yes	1.5	3.0	0	4.2	55	180	2-1-7	1.06	4,850	4,300	16	13
75.3	Yes	1.5	0	1.5	4.1	64	180	2-1-7	1.05	5,120	4,600	28	18
75.3	No	1.5	0	3.0	4.2	33	180	2-1-7	1.07	4,120	3,600	21	17
81.7	No[6]	0.75	0.75	0	4.3	25	195	2-1-7	0.98	3,580	3,700	64	41
81.7	Yes	0.75	1.5	0	4.4	39	195	2-1-7	--	--	--	37	29
81.7	No[6]	0.75	0	0.75	4.4	23	195	2-1-7	1.01	4,460	4,400	64	38
81.7	Yes	0.75	0	1.50	4.2	38	195	2-1-7	--	--	--	37	25
75.3	No	0.75	1.5	0	4.2	33	240	1-2-7	1.08	5,800	5,000	17	10
75.3	No	1.5	1.5	0	4.1	37	240	1-2-7	1.04	4,700	4,300	21	11
81.7	No[6]	0.75	0.75	0	4.3	26	240	1-2-7	0.99	4,820	4,900	25	13
81.7	Yes	0.75	1.5	0	4.4	46	240	1-2-7	1.04	6,030	5,600	19	12

[1] Stocks sized at a consistency of approximately 2 pct.

[2] Maximum and minimum pressures were 500 and 100 lb/in.^{2}, respectively.

[3] The first number represents the initial period at maximum pressure; the second number, the breathing period at the minimum pressure; and the third number, the final period at maximum pressure.

[4] Adjusted to specific gravity of 1.0 on the basis that the modulus of rupture varies as the square of the specific gravity.

[5] Determined by measurements before and after soaking.

[6] Pulp washed with hot water before preparation of board stock. The loss of 2.3 pct of solubles did not materially affect the properties of the hardboards.

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Other Additives

An ever-present goal in hardboard manufacturing is to make stronger and more moisture-resistant boards. One way of doing this during hardboard manufacture is through additives such as phenolic resins, petrolatum, cationic resins, linseed oil, an oil diluent, paraffin, and different fixing agents (Schwartz 1963a, Schwartz and Chilson 1959). Another approach is to take various electrolyte solutions and soak pressed hardboard in them for various time intervals, followed by heat-treatment. Unfortunately, as Torres and Schwartz (1957) showed, these electrolytes are acidic, which causes considerable springback, and reduction of density and strength. All of these approaches have been tried only with wet-formed hardboard.

Nelson (1973) encountered problems in utilizing certain species in dryformed hardboard, and identified fiber pH as a significant factor. Myers (1977, 1978) tried to overcome this problem by adding different amounts of caustic or acid to the dry fiber before spraying phenolic resin onto the fiber.

Laundrie and others (1979) and Myers and Holmes (1975, 1977) attempted to make hardboard more fire-retardant and decay-resistant by adding various fire retardants or different concentrations of preservatives to the dry fiber during hardboard manufacture. These procedures are applicable only to the dry-forming process. One of the biggest problems encountered was incompatibility of additives and phenolic resins. As a result, either resin cure was inhibited, giving a very weak hardboard, or the cure was speeded up so much that the board charred during hot pressing, resulting in a very brittle hardboard. Care had to be exercised with any additive to make certain no compatibility problems arose between the additive and phenolic resin, otherwise the result was hardboard with substandard properties.

Forming Procedures

There are opportunities during the forming operation to do some things that alter hardboard performance. Rosenfeld (1959) made a study in which hardboard fibers were formed into thin sheets on the paper machine, and then cross-laminated and hot-pressed to form a hardboard. Unfortunately the properties were no different from conventionally wet-formed and pressed hardboard. While making dry-formed hardboard, Steinmetz (1977) placed a layer of glass scrim fabric on both sides of the fiber mat before hot-pressing. During hot-pressing the glass fiber was bonded to the hardboard. This imparted greater dimensional stability and strength to the high-density hardboard, but involved some extra steps in the manufacturing process. Another way to impart greater strength and stability to dry-formed hardboard involves orienting (aligning) the fiber during the forming procedure. Steinmetz and Polley (1974) mechanically aligned fibers, either in the same or cross-fiber direction, during the dry-forming operation. Mechanical properties were improved by this alignment (figs. 2 and 3), which involved a more complicated forming process than usual.

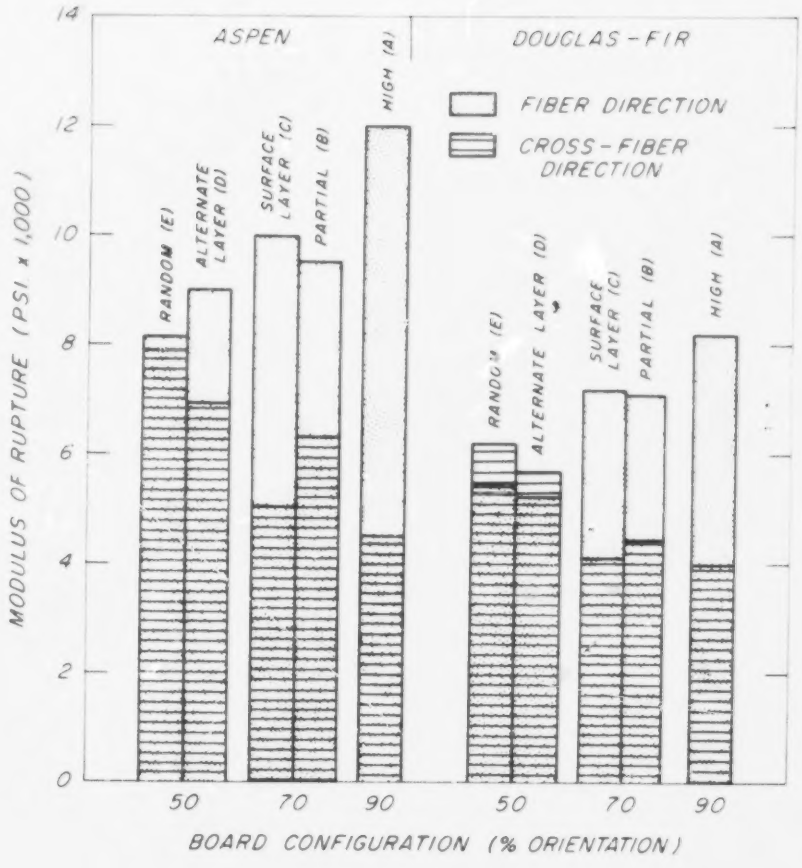

Figure 2.—Relationship of modulus of rupture to quantity and location of oriented fibers of aspen and Douglas-fir high-density hardboards. (A, highly oriented; B, partially oriented—one-half of fibers by weight were oriented; C, partially oriented, oriented fibers concentrated on surface layers, randomly oriented in center half; D, alternate layers oriented, fibers in adjacent layers perpendicular to preceding layer; and E, randomly oriented control board.) Steinmetz and Polley 1974. (M141 025)

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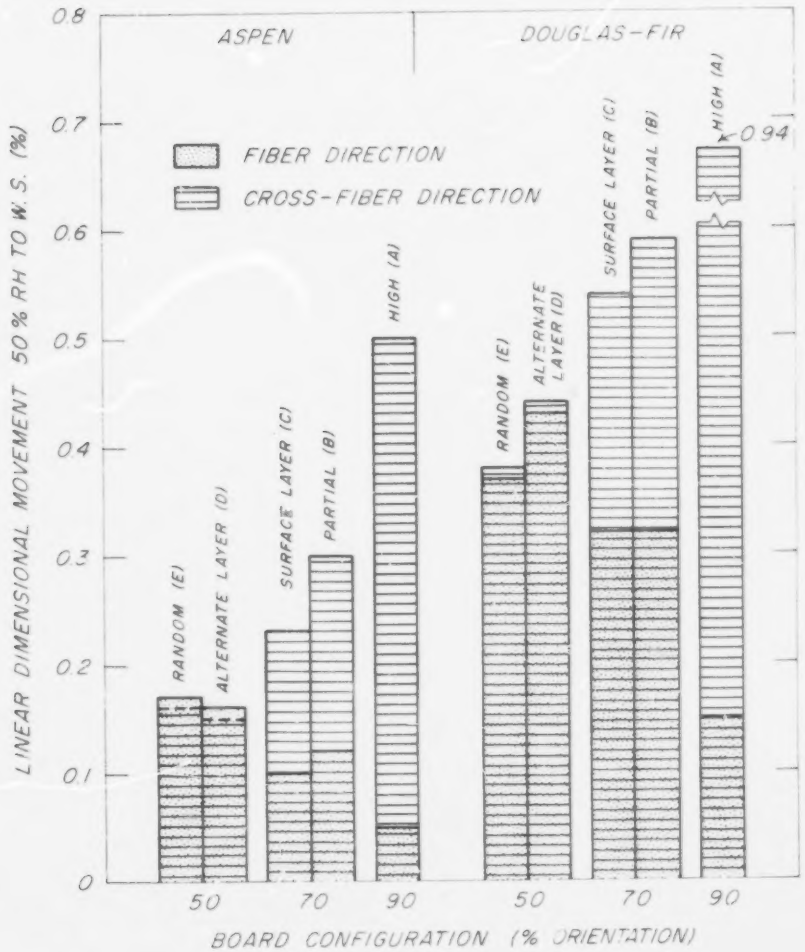

Figure 3.—Relationship of linear dimensional movement to quantity and location of oriented fibers of aspen and Douglas-fir high-density hardboards. (See Fig. 2 legend for Key, A-E.) Steinmetz and Polley 1974. (M141 026)

During hot-pressing, the lignocellulosic mat is consolidated under heat and pressure into hardboard, moisture in the mat is removed, phenolic resin is polymerized, and some naturally occurring bonding takes place because of lignin flow Steinmetz (1970) and Steinmetz and Fahey (1971) showed definitely that temperature of the platens affects the properties of wet- and dry-formed hardboards. When pressing temperature was increased without increasing hardboard specific gravity, there was a general improvement in modulus of rupture (MOR), less water absorption, and less linear movement (fig. 4).

Increasing press temperature usually causes more plasticization of the fibrous mat, and this results in greater hardboard specific gravity (Schwartz and Baird 1950b). When Swamy (1950) combined higher press temperature with higher hardboard specific gravity, strength and stiffness and thickness swelling increased, whereas water absorption decreased. Unfortunately, the resulting hardboards were more brittle.

When hot-press pressure was increased by itself, without a corresponding increase in temperature, the main effect was to increase board specific gravity with slightly improved bending properties. However, Schwartz (1958b) and Turner and Kern (1956) observed no improvement in toughness, water resistance, or thickness change.

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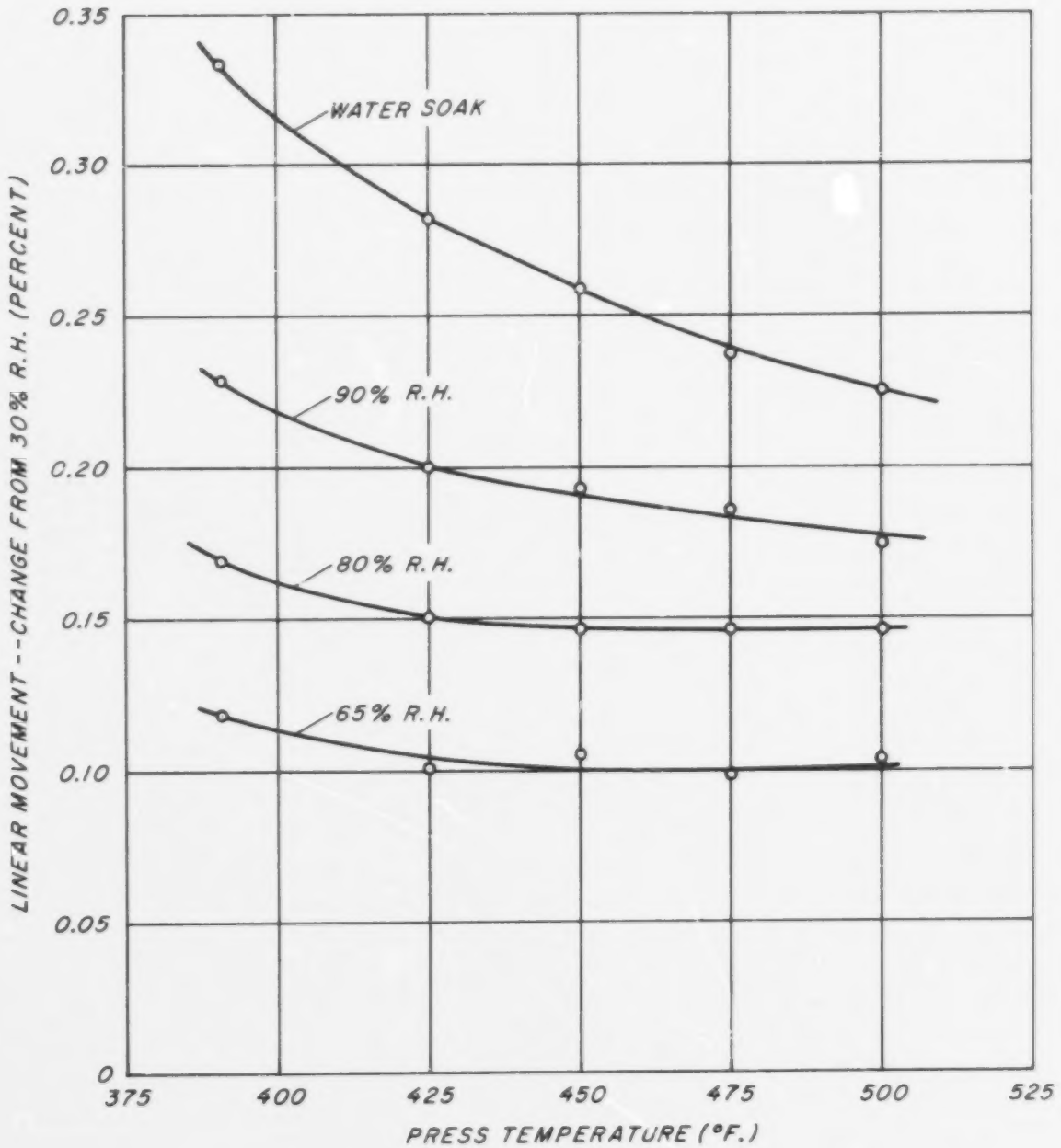

Figure 4.—Relationship between linear movement and hot pressing temperature for 1/8-inch-thick high-density hardboards. Steinmetz 1970. (M137 666)

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Post-Treatment

Heat treatment of hardboard is a common and routinely performed industrial post-treatment. It is done in large ovens, and followed by humidification prior to shipment from the plant. Heat treatment increases strength properties, decreases the amount of moisture absorption and dimensional change, but embrittles the hardboard. Schwartz (1962) conducted the only study at FPL that looked at slightly different ways to heat-treat hardboards, attempting to reach temperatures in excess of 338 °F without igniting the hardboard. He made attempts to use superheated steam, with temperature ranges from 356 to 464 °F, to heat-treat hardboard. Unfortunately, he found heat treatment at the higher superheated steam temperatures was ineffective in reducing water absorption. However, heat treatment in air at 329 °F was effective in improving hardboard properties.

Another procedure commonly utilized to improve hardboard performance is to add various oils to the hot board from the press, before it is heat-treated. Nothing was done at FPL to find new oil formulations for the tempering process. Two studies were conducted to find substitutes or alternatives to tempering oils. One of these (Schwartz and Chilson 1959) involved the addition of cationic resins during hardboard fabrication. This resulted in a hardboard with a more uniform impregnation than obtainable with tempering oils, but the hardboards were not as strong or dimensionally stable as when tempering oils were used. The other (Torres and Schwartz 1957) added several water-soluble electrolytes to the pressed hardboard and heat-treated afterwards. This was not very successful because the electrolyte treatment caused swelling, and the heat treatment resulted in weight loss from the hardboard.

Another post-treatment investigated for improving hardboard that had not been heat-treated involved the use of acetic anhydride vapors. Klinga and Tarkow (1966) treated the hardboards to a 5 percent level with vapors, then heated them for 16 hours at 212 °F to remove all excess chemicals. This treatment resulted in some thickness swell, some linear expansion of the hardboard, and a slightly roughened surface. On the positive side, the treatment reduced hardboard equilibrium moisture content (EMC), reduced linear and thickness movement, and increased tensile strength.

Correlation Between Manufacturing Variables and Hardboard Performance

Turner and others (1948) examined 14 different relationships between manufacturing variables and hardboard performance. These included different conditions affecting drainage rates, pulp mat solids contents, dry mat specific gravity, and performance of the resultant hardboard.

Millett and Hohf (1948) were concerned with how hardboard performed when used as a core covered with veneer or plywood. By realizing some of the properties and limitations built into hardboard, they demonstrated it was possible to cut and reorient the resultant strips in such a manner that dimensional movement is not a problem in performance of the completed panel product.

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Equilibrium Moisture Content (EMC)

High temperatures used in manufacturing cellulosic fiberboards and hardboards decrease the hygroscopicity of the wood fibers. Thus, the EMC of these wood fibers is lower than that of solid wood, particularly at higher humidities. Table 8 lists approximate ranges of EMC for cellulosic fiberboard (Nordenson 1965) and for hardboard (McNatt 1969a, 1973, 1974; Nordenson 1965). In all cases EMC was reached by adsorption from ovendry, or near ovendry, conditions. For comparison, adsorption values for solid spruce wood (Stamm 1964) are included in table 8.

Because of sorption hysteresis effects, EMC values reached from a higher moisture condition (desorption) are considerably greater than adsorption EMC values. For example, figure 5 (McNatt 1969a) shows the hysteresis effect for a medium-density hardboard.

The time to reach equilibrium at a given relative humidity (RH) depends on the rate of diffusion of water vapor into the material and the amount of initial-to-final RH change. Hardboard and cellulosic fiberboard diffusion rates are controlled primarily by panel density. As Heck (1937) showed, cellulosic fiberboard may reach equilibrium in a week or so when moved from a 30 percent RH environment to a 90 percent RH environment. In contrast, hardboard may take a month or more to reach EMC (McNatt 1982).

Table 8.—Range of equilibrium moisture contents (EMC) of fiberboard and hardboard at different relative humidities as compared to that of solid wood[1]

Relative humidity	Equilibrium moisture contents		Solid wood (spruce)[4]
	Fiberboard sheathing[2]	Hardboard[3]	
	Pct		
30	3.4– 6.1	2.4– 5.3	5.3
50	4.4– 7.7	3.2– 6.8	8.3
65	5.3– 9.9	5.1– 8.1	10.6
80	—	8.5–11.5	14.1
90	9.2–17.0	9.0–14.9	17.9

[1] All materials conditioned to EMC at the various relative humidity exposures from at or near ovendry condition (adsorption).

[2] From Nordenson 1965.

[3] From McNatt 1969a, 1973, 1974, and Nordenson 1965.

[4] From Stamm 1964.

Linear Expansion

Linear expansion of hardboard and cellulosic fiberboard does not appear to be influenced as much by panel density as by various other manufacturing and raw material variables. Between 30 and 90 percent RH, the ranges of linear expansion reported are: 0.20-0.47 percent for cellulosic fiberboard (Luxford 1955, McNatt 1982, McNatt and Lewis 1966 and 1967), 0.15-0.52 percent for hardboard (McNatt 1969a, 1982; Werren and McNatt 1975), and 0.35-0.62 percent for MDF (Laundrie and McNatt 1975, Superfesky and Lewis 1974).

McNatt (1973) has found that buckling (Y) of 16-inch-long hardboard siding strips, restrained at the ends to restrict linear expansion, can be related to unrestrained linear expansion (L), specific gravity (G), and board thickness (t). The equation developed for 35 different hardboards was:

$$Y = 0.658 \log_{10} \frac{GL}{t^2} + 0.044 \qquad (1)$$

$$(r^2 = 0.94)$$

Water Adsorption and Thickness Swelling

The FPL has gathered very little water adsorption and thickness swelling data on wood fiber products. Luxford (1955) reported less than 2 percent increase in weight after 2 hours soaking for 14 different cellulosic fiberboard sheathing products treated with asphalt to retard moisture pickup. He also reported an 8 percent increase for 6 hours soaking and 35 percent increase for 48 hours soaking. McNatt (1969a) reported that medium-density hardboard soaked for 2 hours increased 2.8 percent in weight and 1.2 percent in thickness. Soaked for 24 hours, it increased about 8 percent in weight and about 6 percent in thickness. Superfesky and Lewis (1974), using three commercial MDF products soaked for 24 hours, found increases in weight varying from 8.8 to 12.5 percent and in thickness from 2.8 to 4.2 percent.

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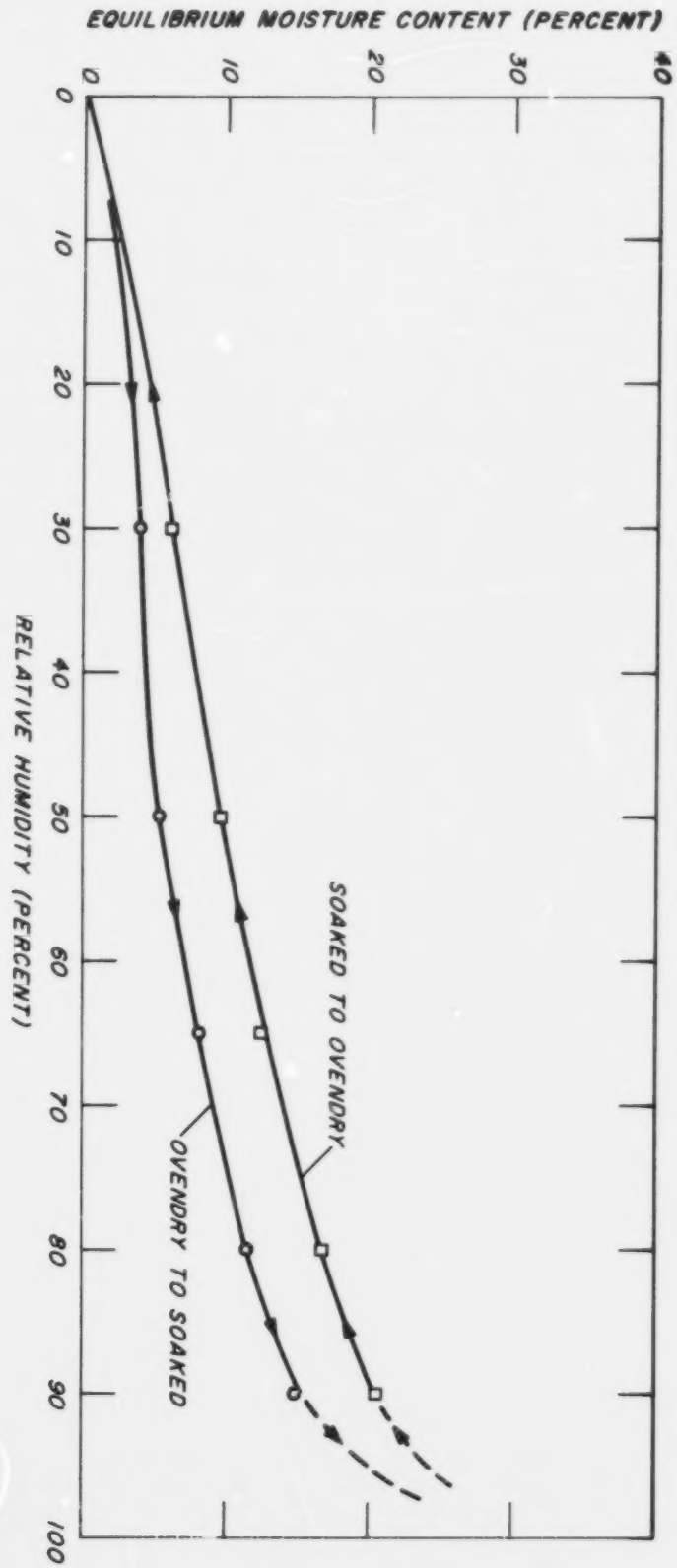

Figure 5.—Relationship of equilibrium moisture content to relative humidity for a 3/8-inch-thick medium-density hardboard initially ovendried (adsorption) and initially soaked to near saturation (desorption). McNatt 1969a. (M137 064)

It should be pointed out here that as wet-process cellulosic fiberboard and hardboard mills attempt to reduce effluent pollution, water adsorption and dimensional stability are adversely affected. Effluent discharge limitations are met by recycling process water which increases the concentration of dissolved solids and fines in the product. Therefore, hardboard and cellulosic fiberboard values quoted above may not be relevant for current production.

Thermal Conductivity

Lewis (1967) conducted a major thermal conductivity study of wood-base panel products. Using the ASTM Standard C 177 guarded hotplate apparatus, he evaluated fiber-based panels ranging from 1.6 to 62.3 lb/ft^3 and developed the design curve shown in figure 6. The curve is based on a mean temperature of 75 °F. The values should be increased or decreased 0.00053 for each degree increase or decrease in mean temperature (see fig. 6 for units).

Dielectric Properties

James (1975) reported values for two dielectric properties of 1/4-inch hardboard. Dielectric constant—ability of a material to absorb and store energy, and loss tangent—rate of energy loss in the material. He found that dielectric constant and, with a few exceptions, loss tangent perpendicular to the panel face increased as moisture content and temperature increased, and decreased as the frequency of the electric field increased. At frequencies of 1 to 50 kHz, hardboard values were very close to solid Douglas-fir and oak across the grain. At lower frequencies, values diverged.

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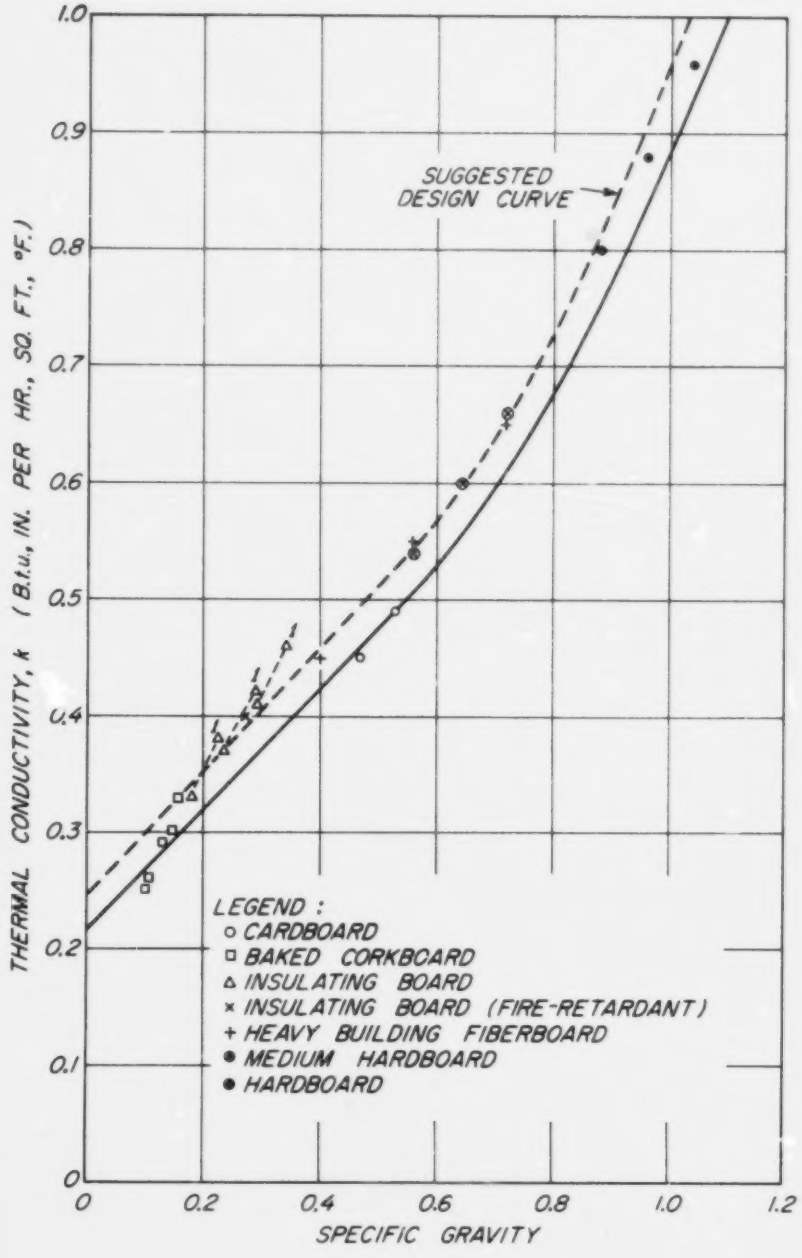

Figure 6.—Relationship between thermal conductivity and specific gravity for wood-base fiber materials and suggested design curve. Lewis 1967. (M132 875)

Fire Performance

Several studies over the past 40 years have investigated the fire performance of cellulosic fiberboard and hardboard and the effects of fire-retardant treatments. Van Kleeck and Martin (1950) compared small vertical, inclined, and horizontal panel tests to evaluate the flamespread resistance of interior finish cellulosic fiberboard. They found reasonably good correlation between the methods, but did state that it would be difficult to predict performance in one of the tests from performance in either of the other two tests. Bruce (1953) reported that interior-grade cellulosic fiberboard performed about the same as Douglas-fir plywood as wall and ceiling covering in a series of experimental dwelling-room fires. He concluded from these tests that room furnishings were a bigger factor in room fires than wall and ceiling covering. Fire flashover occurred about the same time whether the wall and ceiling coverings were cellulosic fiberboard, plywood, or gypsum board.

Schaffer and Eichner (1965) reported the same flashover time for a partially ventilated corridor whether the walls were lined with plaster, with wood wainscoting, prefinished hardboard paneling, or red oak lumber.

Brenden and Schaffer (1980) proposed a simple test to compare smoldering tendency of cellulosic fiberboard. Smoldering of cellulosic fiberboard used as sound insulation in walls (sound-deadening board) can result from careless use of soldering torches when installing plumbing. Van Kleeck and Sandberg (1949) had earlier found boric acid to be superior to monoammonium phosphate in retarding smoldering.

Myers and Holmes (1975, 1977) showed that dry-formed hardboard flamespread could be reduced significantly by adding fire-retardant chemicals during manufacture. Flamespread index of untreated panels averaged about 180. Panels made from treated fiber averaged about 50 to 60 which meets the 75-or-under flamespread criterion for Class B material.

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Mechanical Fastener Performance

Acoustical Absorption and Sound Transmission

Depending upon board type and method of application, cellulosic fiberboards and hardboards can be effective in the two major areas of noise control in buildings; isolation from external sound and absorption of internal sound. FPL scientists have developed some information in both areas. Godshall and Davis (1969) used the ASTM C 384 impedance tube method (ASTM 1977) to compare sound absorption characteristics of wood-base materials including wood-fiber matting, cellulosic fiberboard ceiling tile, and hardboard. Perforated hardboard, backed with a 1-inch fiber mat, appeared to perform best; even better than porous acoustical ceiling tile.

Jones (1975a, 1975b; 1978) demonstrated that both hardboard and sound-deadening cellulosic fiberboard can be used to reduce sound transmission through walls. At the same time, he pointed out that construction practices can be at least as important as construction materials in reducing sound transmission.

Screwholding

Resistance to direct screw withdrawal is relevant only for those fiberbase panel products used in furniture and cabinet making. This applies almost exclusively to MDF about 3/8 inch thick or greater. Superfesky (1974) measured maximum direct screw withdrawal resistance on three commercial MDF products using 1-inch-long, No. 10, Type A and Type AB tapping (sheet metal) screws. In all cases the Type A screw gave withdrawal resistance values at least 10 percent greater than the Type AB screw. As expected, both face and edge withdrawal resistance increased as panel density increased (fig. 7). Laundrie and McNatt (1975) measured maximum screw withdrawal resistance of No. 10, Type A screws from 3/4-inch-thick MDF panels made from urban wood waste (dismantled wood railroad cars, used pallets, dead elm trees, and wastepaper). Face withdrawal resistances ranged from 198 to 432 pounds and edge withdrawal resistances ranged from 161 to 355 pounds. At equivalent densities, values were below those for commercial MDF panels.

Lateral Nail Resistance

Probably the most important property of cellulosic fiberboard sheathing is resistance to lateral movement of a nail toward the panel edge (fig. 8) since it is directly related to wall racking resistance.

Lewis (1962b) measured the maximum lateral nail resistance of 47 different cellulosic fiberboard sheathing products: 1/2- and 25/32-inch-thick regular-density (0.26-0.35 specific gravity (sp. gr.)), 1/2-inch-thick intermediate-density (0.30-0.41 sp. gr.), and 1/2-inch-thick nail-base (0.36-0.43 sp. gr.). Eleven-gage galvanized roofing nails and a 3/4-inch edge distance were used. Lewis reported that lateral nail resistance per inch of panel thickness (LNR/T) varied directly with panel specific gravity (G). Least squares regression of all 282 specimens gave the relationship:

$$LNR/T = 1263G - 198 \qquad (2)$$

$$(r^2 = 0.80)$$

Lewis (1959a) found a similar relationship for a pilot-plant manufactured cellulosic fiberboard sheathing with sulfite liquor as a binder and water resistance substance. The regression equation for 90 specimens is:

$$LNR/T = 1221G - 220 \qquad (3)$$

$$(r^2 = .84)$$

Equations (2) and (3) are valid only within the range of specific gravity evaluated; they indicate negative results for specific gravity slightly below 0.2.

Lewis (1963) also reported on a series of lateral nail resistance tests conducted to determine the effect of rate of loading on test results for 25/32-inch-thick regular-density cellulosic fiberboard sheathing. Six-penny common nails were driven 1/2 inch from the edge. Maximum loads for specimens loaded at 2.00 inches per minute were only about 4.5 percent greater than for specimens loaded at 0.25 inch per minute. The slower speed yielded more uniform results.

Wall Racking Strength

Several researchers have used maximum lateral nail resistance to predict racking strength of wood-frame walls sheathed with wood-base sheathing panels. With a limited amount of data, Luxford (1957a) related maximum lateral nail resistance (LNR), in pounds, of cellulosic fiberboard sheathing and racking strength (RK) of 8- by 8-foot wall sections:

$$RK = 29LNR + 2,150 \qquad (4)$$

$$(r^2 = \text{not reported})$$

This appears to be quite different from the relationship found by Neisel and Guerrera (1956):

$$RK = 57.3LNR - 313 \qquad (5)$$

$$(r^2 = 0.90)$$

However, when Neisel (1958) plotted the two sets of data on the same graph (fig. 9), he found a common linear relationship:

$$RK = 46.4LNR + 736 \qquad (6)$$

$$(r^2 = 0.83)$$

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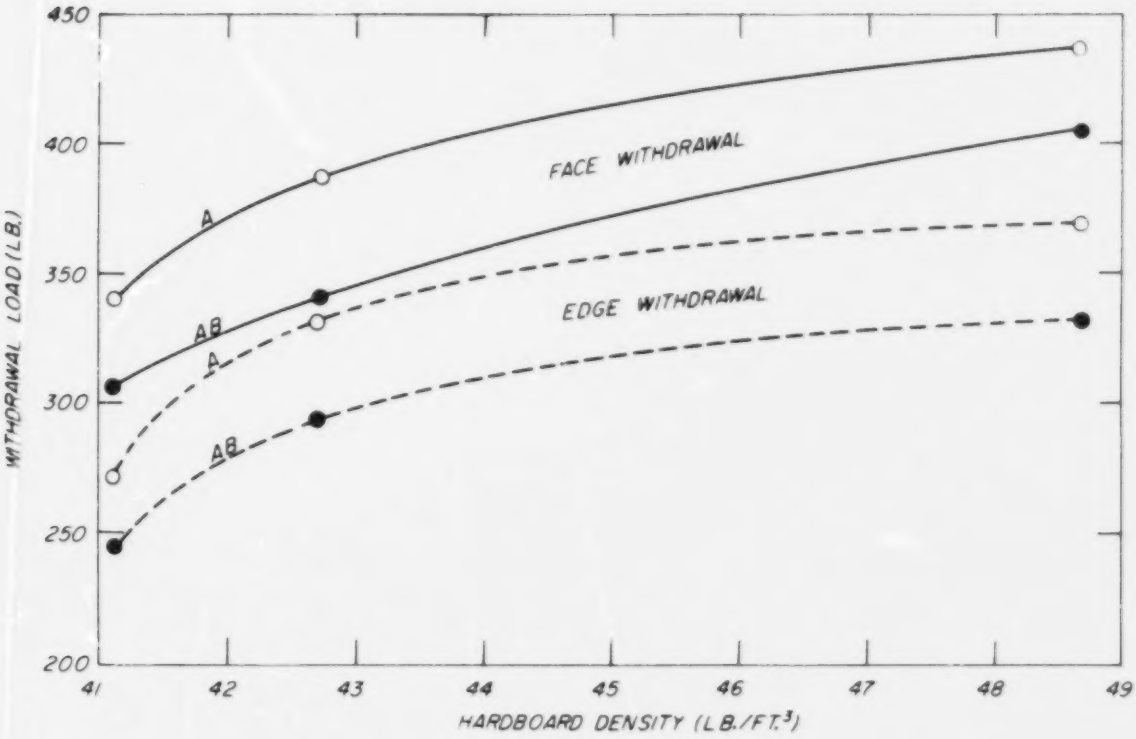

Figure 7.—Face and edge screw withdrawal loads of type A and AB tapping screws for different MDF densities. Superfesky 1973. (ML85 5062)

Results from these earlier studies on racking strength were valid for the specific wall dimensions, materials, and nailing patterns used; they indicate widely different values for the racking strength of the wall frame itself (2,150, −313, and 736 lb).

Tuomi and Gromala (1977) presented an equation relating maximum lateral nail resistance of sheathing and wall racking strength which included factors for the number and size of sheathing panels used and nail spacings. They found the racking strength of the wall frame itself to be about 450 pounds. Tuomi and McCutcheon (1978) used this equation to predict racking strength of full-size (8- by 8-ft) wall sections and more economical 2- by 2-foot sections. The study confirmed that the equation is independent of panel size. This equation is also plotted in figure 9 for the same wall section construction used by Luxford and by Neisel and Guerrera, except that Tuomi and Gromala used 11-gage galvanized roofing nails instead of 8d common nails and a 3/4-inch edge distance in the lateral nail tests instead of 1/2 inch. They felt the 3/4-inch edge distance best represented displacement of critical perimeter nails in a racking test. In actual practice, half the perimeter nails move inward relative to the panel edge, so edge distance is critical only for the other half of the perimeter nails. Variation of edge distances probably accounts for most of the difference between the two lines in figure 9. Tuomi and Gromala (1977) determined the relationship between edge distance and maximum lateral nail resistance for four types of cellulosic fiberboard sheathing (fig. 10). Luxford (1955) found that resistance for 3/4-inch edge distance averaged about 75 percent greater than for 3/8-inch edge distance.

In 1937 Heck conducted wall racking tests on wall sections sheathed with 25/32-inch cellulosic fiberboard to determine strength and rigidity and to evaluate effects of nail spacing, high humidity exposure, and window and door openings. Industry-recommended nailing called for 8d nails at 3-inch intervals along the perimeter framing and 6-inch intervals along the intermediate studs. Test results showed that:

- When window and door openings were included, wall strength and stiffness decreased more than 50 percent.
- When double the recommended number of nails were used, strength and stiffness increased about 50 percent for walls without openings and 20 to 40 percent for walls with openings.

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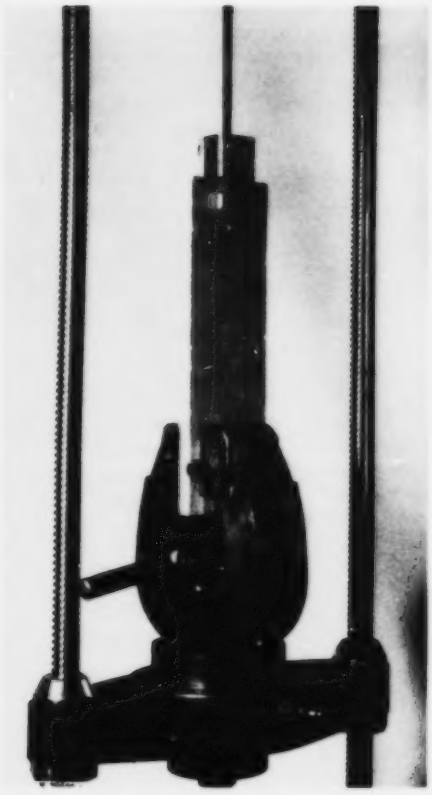

Figure 8.—Test setup for measuring lateral nail resistance of fiberboard according to ASTM Standard D 1037. (M766 00)

- Tests showed that strength and stiffness of walls decreased about 15 percent during a month at 40 °F and 94 percent RH; they decreased about 20 percent during a 24-hour water spraying.

Soltis and others (1983) included a table of comparative racking strength of 8- by 8-foot wood-frame walls with plywood, flakeboard, or cellulosic fiberboard sheathing. It is interesting that the wall section with 1/2-inch nailbase cellulosic fiberboard sheathing carried the greatest load (6,380 lb). Nail spacings were 3 inches, perimeter, and 6 inches, interior, for the cellulosic fiberboard and 6 inches/12 inches for the flakeboard and plywood, according to industry recommendations. Strength and stiffness of flakeboard and plywood walls could be increased significantly by increasing the number of nails.

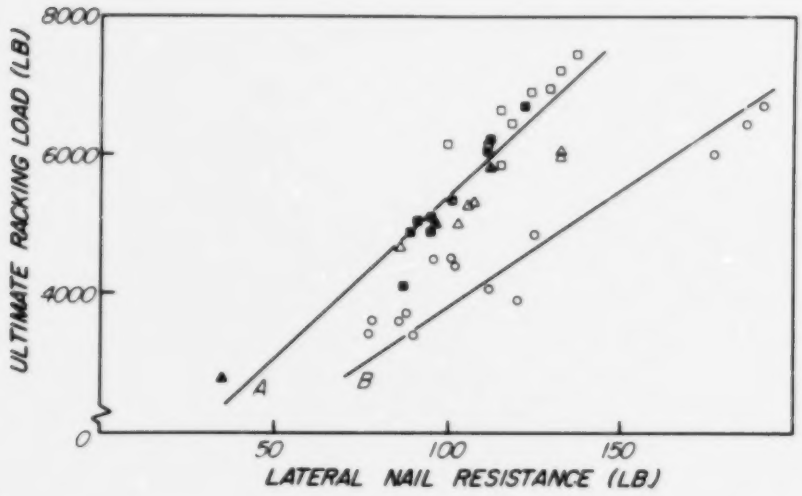

Figure 9.—Relationship between lateral nail resistance of fiberboard sheathing and racking resistance of walls sheathed with fiberboard. (ML85 5063). The equation for line A is from Neisel and Guerrera (1956), with data points from Luxford (1957a) (Dry Δ, Wet ▲) and Neisel and Guerrera (1956) (Dry □, Wet ■). Equation and data points (Dry O) for line B are from Tuomi and Gromala (1977).

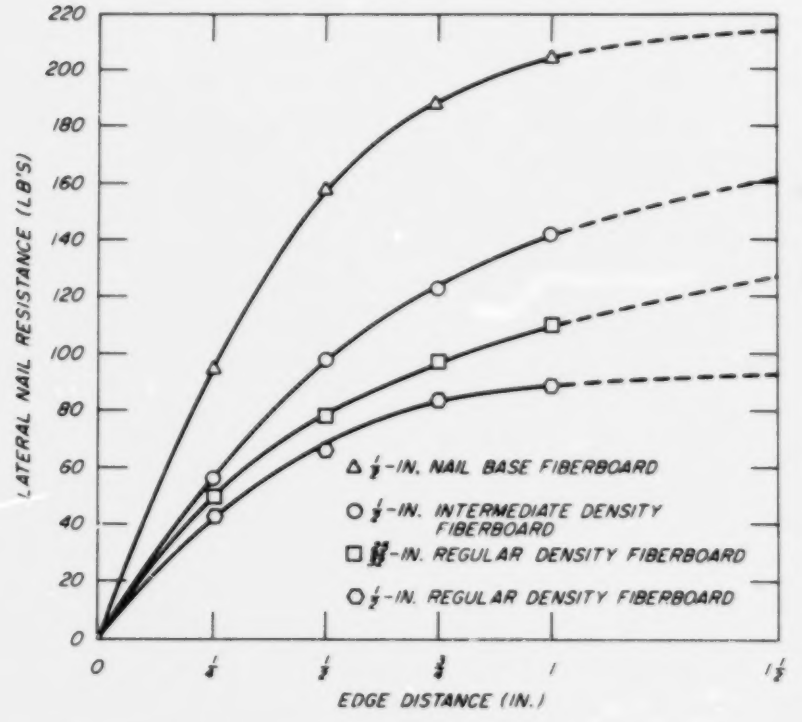

Figure 10.—Lateral nail resistance at various edge distances for four types of cellulosic fiberboard. Tuomi and Gromala 1977. (M144 300)

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Gounaris (1964) tested wall panels sheathed with 1/4-inch tempered hardboard to determine resistance to earthquake-type forces. Maximum racking strength for 8- by 8-foot wall sections ranged from 9,100 pounds for panels with hardboard nailed to one side to more than 28,000 pounds for a wall section with hardboard nail-glued to both sides. Cyclic-load racking indicated that walls sheathed on both sides with hardboard could well resist severe earthquake loads.

Load-bearing walls must not only meet code requirements for maximum load, but also maximum allowable deflection at given load increments. Wilkinson (1972, 1974) developed theoretical methods for predicting load-deformation characteristics of a nailed lap joint of one solid wood member (framing) and one sheathing material member, including cellulosic fiberboard and hardboard siding. The predicted slope of the load-slip curve (fig. 11) is based on a material property called "elastic bearing constant" and is useful in evaluating the stiffness of nailed joints between framing and sheathing in walls, roofs, and floors. McCutcheon (1985) developed the theory to define racking deformation of wood stud walls as a function of the lateral nonlinear load-slip behavior of the nails.

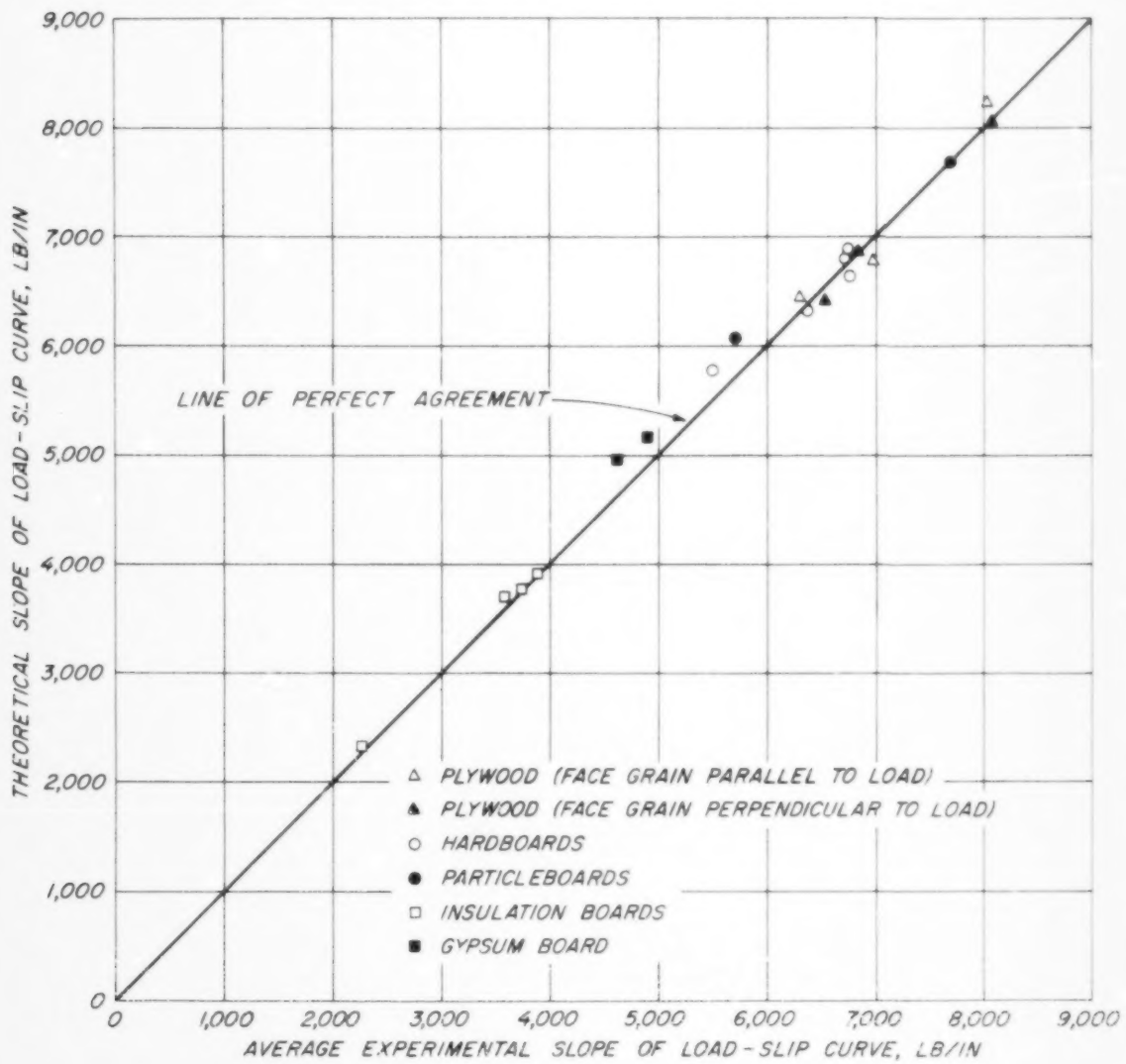

Figure 11.—Theoretical versus experimental slopes of the load-slip curve for joints with one member of Douglas-fir lumber and one member of panel material. Wilkinson 1972. (M141 657)

Lateral Staple Resistance

Since staples are being used increasingly in place of nails to attach sheathing to wood framing, information on resistance to lateral movement of staples in various sheathing materials is needed. Lewis (1962a) developed a test for measuring lateral staple resistance of cellulosic fiberboard sheathing (fig. 12). With nail-base cellulosic sheathing and 16-gage, 1-1/2-inch-long staples, maximum loads were comparable to those of 11-gage roofing nails tested by the standard ASTM procedure (fig. 8). Staple tests with 25/32-inch regular-density cellulosic fiberboard sheathing gave somewhat lower values than nail tests because the staple crown was pulled into the face of the panel. This is, in fact, the type of failure expected in racking tests of wall panels sheathed with stapled-on regular-density cellulosic fiberboard.

Chow and others (1984) reported that the maximum lateral resistance of a 16-gage staple in a hardboard siding averaged about 75 percent of the maximum lateral resistance of a 6d nail.

Figure 12.—Test setup for measuring lateral staple resistance of fiberboards. Lewis 1962a. (M121 368)

Hardboard Glue-Bond Strength

Hardboard and other wood-base panels are sometimes bonded together or to other materials, when manufacturing furniture and casegoods. Bond strength is affected by a number of factors. For example, using heat to accelerate setting of water-base glues creates steep moisture gradients in the material adjacent to the glue line at the time the glue sets. As the moisture dissipates, internal stresses are set up which can actually cause bond failure without added outside forces (Lewis 1968b). Anderson (1969) demonstrated that hardboard type, moisture content, type of glue, and failure location interact to affect glue-line shear strength. For example, glue type affected bond strength more in untempered than in tempered hardboard. Shear strength was generally greater when the failure occurred in the body of the board rather than at, or adjacent to, the glue line. In turn, glue type influenced failure location.

Hardboard Machining Properties

Davis (1957) conducted a series of nine different tests to compare machining properties of various hardboards. He concluded that the main problem in machining hardboard was relatively rapid dulling of cutting tools. Carbide-tipped tools could largely solve this problem. Common defects were fuzzing and chipping. Hardboard was less subject to some machining problems than lumber because it has no grain direction.

Basic Strength and Elastic Properties

Except for one extensive study on hardboard in the 1960's (McNatt and Lewis 1963-70), very little work has been done on the basic strength and elastic properties of commercial hardboards and fiberboards. Probably most of the property values from that study are not relevant for current production because stricter water treatment requirements have necessitated manufacturing changes. The same is true for Luxford's (1955) data on bending strength of 14 commercial cellulosic fiberboard sheathing products and the effects of water soaking.

Lewis (1959b) evaluated the structural properties of 1-1/2-, 2-, and 3-inch laminated cellulosic fiberboard roof deck panels from 13 manufacturers. Bending loads at failure were 7 to 11 times design loads and calculated deflections at design loads were less than span/300. All panels retained at least 55 percent of original bending strength after accelerated aging. Lewis also measured resistance to impact and concentrated load and creep under continuous load. This work was the basis for standard cellulosic fiberboard roof deck tests (ASTM 1983).

More recently Superfesky and Lewis (1974) determined the basic properties of three commercial MDF products (called "medium-density hardboard" in their report). Some average property values are:

MOR = 4,700-5,000 lb/in.^{2}

MOE = 500,000-520,000 lb/in.^{2}

Tension parallel strength = 2,500-3,000 lb/in.^{2}

Compression parallel strength = 3,000-3,600 lb/in.^{2}

Internal bond strength = 130-190 lb/in.^{2}

Hardness = 1,500-2,300 lb

The above property values are probably still valid for current production.

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Laundrie and McNatt (1975) reported properties of MDF made from urban wood waste. Performance levels of a few specific board types bettered those of commercial MDF panels, but for the most part levels were lower.

Lewis (1971) evaluated the bending properties and hardness of 13 commercial hardboard siding products and two other fiber-based siding materials. Hardboard sp. gr. ranged from 0.60 to 0.88, MOE from 189,000 to 594,000 lb/in.^{2}, MOR from 1,630 to 5,030 lb/in.^{2}, and hardness from 490 to 2,080 pounds. Measurement of the two other fiber-based siding materials (one of repulped newsprint, the other of laminated paperboard) gave the following values: sp. gr., 0.40 and 0.52; MOE, 88,000 and 370,000 lb/in.^{2}; MOR, 670 and 1,600 lb/in.^{2}; and hardness, 185 and 300 pounds.

Lewis (1968c) developed a hardness modulus test as an alternative to the ASTM standard Janka ball hardness test for wood and wood-base materials. Hardness modulus is the ratio of load to depth of penetration using the same 0.444-inch-diameter steel ball as in the standard test. Equivalent Janka ball hardness is estimated by dividing hardness modulus by 5.4. Hardness modulus, particularly suited to thin panels, is now included in ASTM Standard D 1037 (ASTM 1978b).

McNatt (1969b) developed a rail shear test (fig. 13) suitable for determining edgewise shear strength (fig. 14) of hardboard and other wood-base panels. The test was incorporated into ASTM D 1037 and was used to measure shear strength of hardboards used in built-up I-beams discussed later in this report.

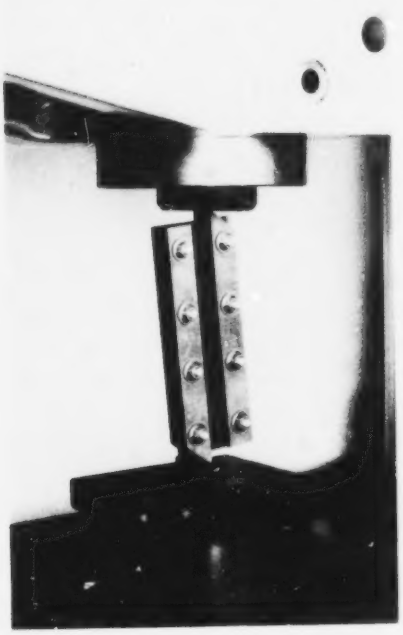

Figure 13.—Rail shear test setup for measuring edgewise shear strength of hardboard. ASTM Standard D 1037. (M125 798)

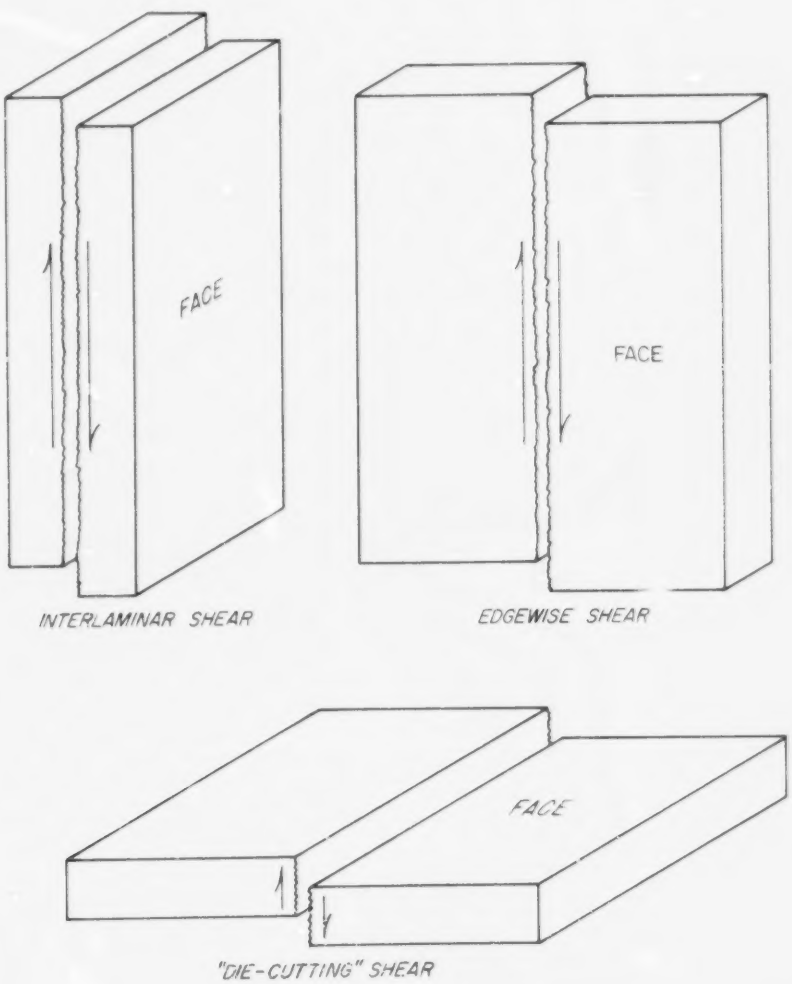

Figure 14.—Three basic shearing directions for hardboard (character of failure not necessarily as shown). McNatt 1972. (M139 209)

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Effects of Loading Conditions and Specimen Dimensions on Mechanical Properties

Hardboards are sometimes subjected to what is called "die-cutting" shear (fig. 14) when cutting to size or when producing cut-outs in radio and TV backs, filigree panels, and perforated panels (pegboard). McNatt (1972) compared two test methods for measuring die-cutting shear strength of hardboard; the Johnson double-shear tool and the Standard D 732 (ASTM 1946) for plastics. Shear strengths, which were about the same for both tests, ranged from 2,300 to 4,500 lb in.$^{-2}$ depending on panel density and thickness. The ASTM D 732 method, which cut a round plug, was judged better for hardboard because it produces a sharper failure and averages any board directional properties.

Fatigue (repeated loading) testing of wood-base products is primarily a research tool to help predict long-term loading behavior. McNatt (1970) found that fatigue strengths of 1/4-inch-thick tempered hardboard for 10 million cycles of stress in tension and shear were about 45 percent of static strength, about the same as solid wood and particleboard.

A number of studies have investigated the effects of testing speed on measured strength of hardboards and cellulosic fiberboards (Lewis 1953, 1955; McNatt 1970; Youngquist and Munthe 1948). In three of these only bending strength was measured. In a fourth (McNatt 1970), tension, compression, and shear strength were also measured. In all cases, results agreed with previously published information on solid wood. That is, strength decreased 6 to 10 percent for each tenfold increase in time to maximum load. The bending specimen size and rate of loading requirements currently in ASTM D 1037 are based on the recommendations of Youngquist and Munthe.

Lewis (1948) investigated the effect of four different specimen types (fig. 15) on the tension parallel-to-surface strength of cellulosic fiberboard sheathing. As a result of this study, type D in figure 15 was selected as the standard for ASTM D 1037.

Clouser (1962) investigated various specimen configurations for measuring compression parallel-to-surface properties of wood-base panels including hardboard and cellulosic fiberboard. Not all products could be evaluated by a single test. He suggested three options for a wide range of densities and thicknesses.

- Short column: Specimen no longer than 4 times panel thickness, for strength only.
- Lateral support: Single thickness of panels thin enough to buckle if loaded as unsupported column, for strength and stiffness.
- Laminated: Several thicknesses laminated together to eliminate buckling, for strength and stiffness.

These three options are now included in ASTM D 1037.

In addition to the rate-of-loading tests McNatt (1970) also conducted stress-rupture tests on 1/4-inch-thick hardboard in tension parallel to surface. He measured time to failure for specimens at constant loads of 90, 80, 70, 60, and 50 percent of static strength. The trends of these stress-rupture data and the rate-of-loading data were used to calculate a hyperbolic curve representing the relationship between stress level (S, in pct) and time to failure (T, in sec):

$$S = \frac{121}{T^{0.047}} \qquad (7)$$

These data together with other such information from England and Sweden were used to derive allowable design values for tempered hardboard now a part of the British Standard Code of Practice on structural use of wood products.

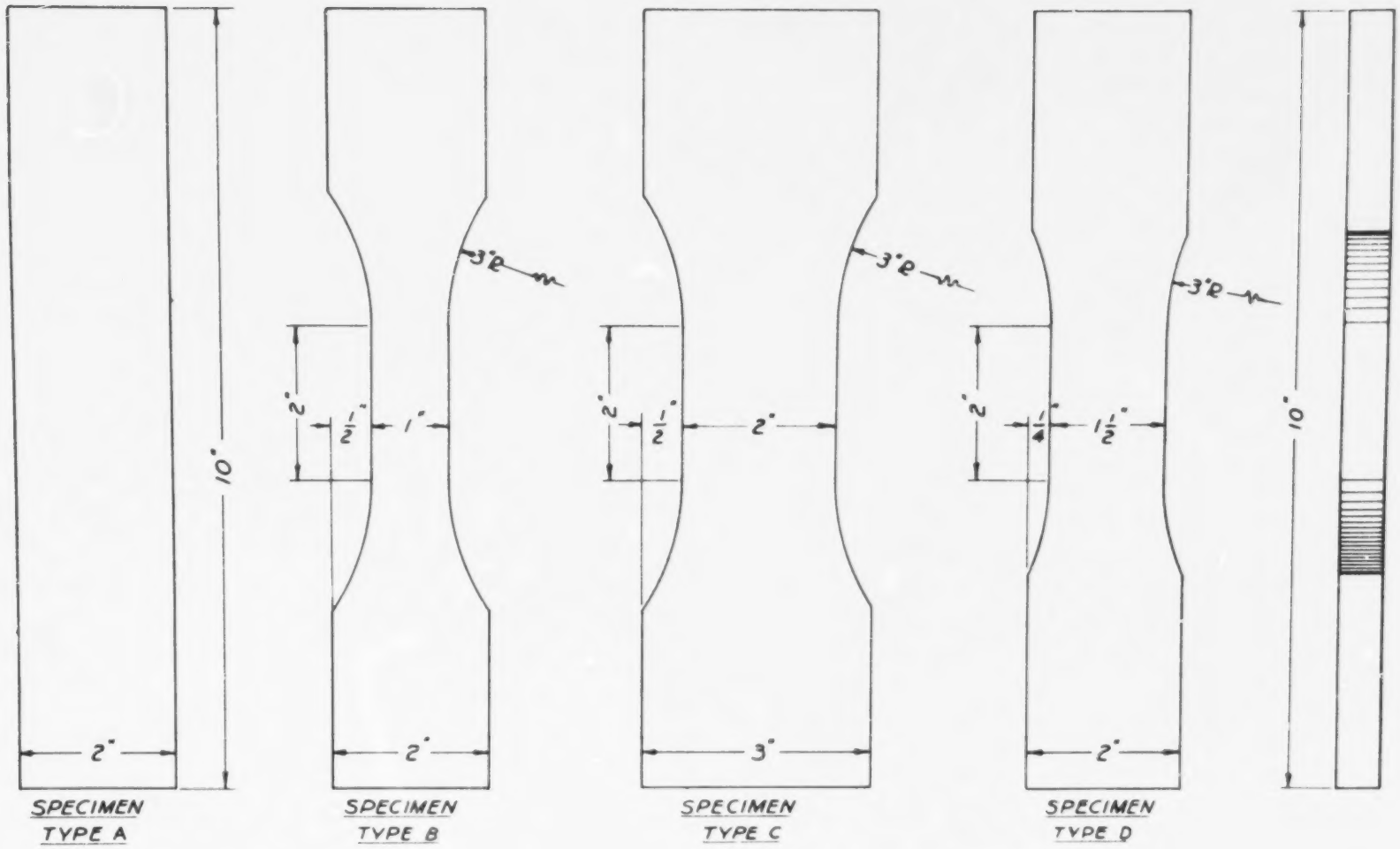

Figure 15.—Details of tension parallel-to-surface specimens for comparative tests on cellulosic fiberboard. Lewis 1948. (ZM777 13F)

Effect of Moisture on Physical and Mechanical Properties

McNatt (1974) investigated effects of changes in equilibrium moisture content (EMC) on the strength and stiffness of six different 1/4-inch-thick tempered hardboards (figs. 16 and 17). The range of average properties, except for interlaminar shear modulus, are shown below as a percent of control values at 65 percent RH.

- 100 to 120 percent between ovendry and 50 percent RH.
- 80 to almost 100 percent at 80 percent RH.
- 70 to 90 percent at 90 percent RH.

Interlaminar shear modulus between ovendry and 50 percent RH averaged 125 percent. It averaged only 70 percent at 80 percent RH and 60 percent at 90 percent RH.

The lines for bending strength and stiffness in figures 16 and 17 agree with work done earlier by Nordenson (1965) on hardboard siding. That is, bending strength and stiffness between ovendry and 50 percent RH were no greater than the control values at 65 percent RH. On the other hand, Nordenson found that cellulosic fiberboard sheathing bending properties in the same humidity range were about 20 percent greater than control values.

McNatt (1982) found that a hardboard siding subjected to 12 cycles of 1 month at 30 percent RH plus 1 month at 90 percent RH retained 95 percent of its original bending strength and stiffness. A cellulosic fiberboard sheathing subjected to the same exposure retained 85 percent of its original bending properties. The results were the same when the cyclic exposure was shortened to 12 repetitions of 1 week at 30 percent RH plus 1 week at 90 percent RH.

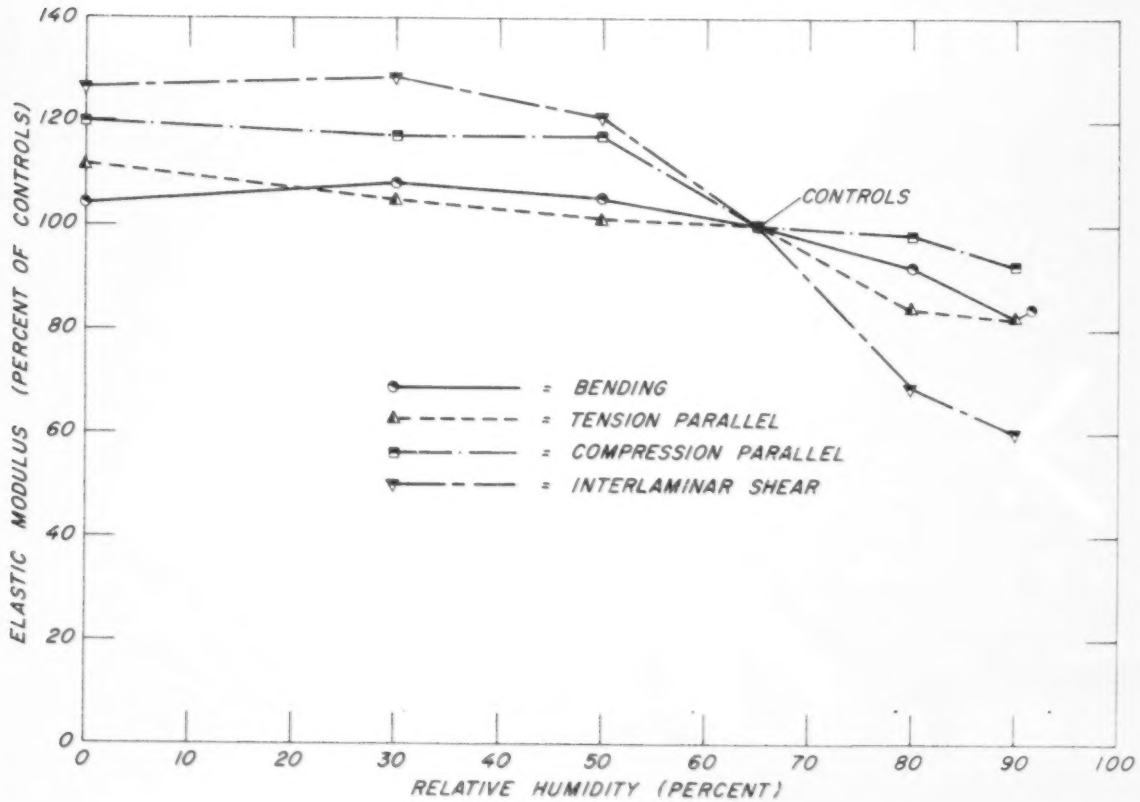

Figure 16.—Average elastic moduli of six 1/4-inch-thick tempered hardboards ovendried and conditioned to equilibrium moisture content at five relative humidities. McNatt 1974. (M141 014)

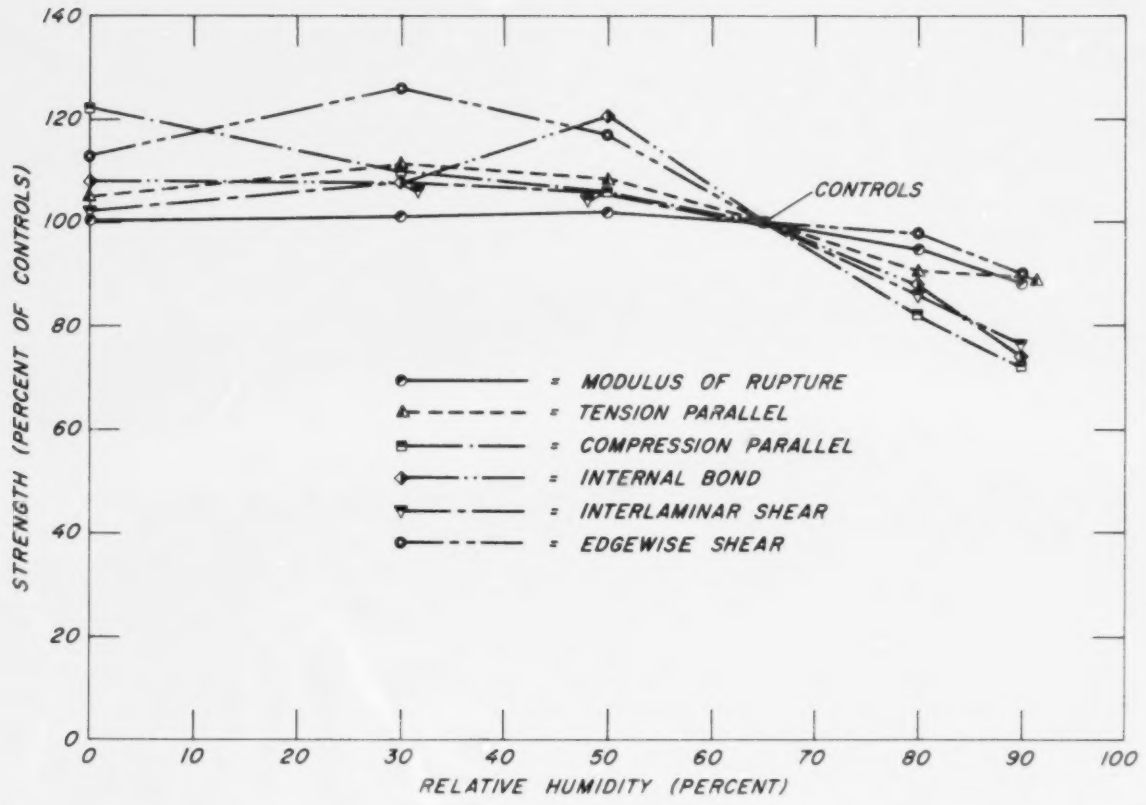

Figure 17.—Average strength of six 1/4-inch-thick tempered hardboards ovendried and conditioned to equilibrium moisture content at five relative humidities. McNatt 1974. (M141 011)

McNatt and Lewis (1966, 1967) related sag deflection of 2- by 4-foot cellulosic fiberboard lay-in ceiling panels at high humidity to sag deflection of 4- by 24-inch strips cut from the panels. For small deflections, sag of the panels and strips were about equal; but as deflections increased, sag of the panels became proportionately smaller compared to that of the strips. Attempts to relate sag to panel properties were unsuccessful because of interactions between linear expansion, panel stiffness, and panel weight. This panel sag test is now included in ASTM C 367 as a standard test method.

Hardboard and Fiberboard Durability

The ASTM D 1037 6-cycle accelerated aging test was used in several studies to evaluate the suitability of cellulosic fiberboard and hardboard for extreme exposure conditions such as exterior siding and roof decking.

Lewis (1968a) used the 6-cycle test to gage the possible deterioration of 15 different hardboard siding products. Most of them were judged suitable for exterior exposure. Several were felt to be unsuitable due primarily to excessive thickness swelling. Myers (1979) tested dry-formed phenolic-bonded hardboards made from tropical hardboards after the ASTM 6-cycle exposure. He concluded that they were sufficiently durable for exterior use. Fahey (1976) reported that phenol-resorcinol-bonded hardboards could be made using high-frequency pressing based on bending tests after the 6-cycle exposure. River and others (1981) compared the ASTM 6-cycle test with two other exposures as a measure of hardboard durability: Up to 80 boil-dry cycles, and up to 40 vacuum-pressure-soak cycles. Relationships between the three tests were not consistent for the four hardboards. Strength retained after the 6-cycle test compared to as few as 2 cycles of the other two tests, or to as many as 35 cycles. Samples of these four hardboards are being exposed to outdoor weathering, but have not yet been evaluated.

Feist (1982) found hardboard siding to have the best overall paint and stain finish performance when compared with solid southern pine boards, Douglas-fir plywood, and aspen waferboard after 52 months of outdoor weathering.

Laundrie et al. (1979) reported that the addition of as little as 0.2 lb/ft^3 of ammoniacal copper arsenate prevents essentially all decay fungi and termite attack during the first year of ground-contact exposure in a severe tropical climate.

Hardboard and Fiberboard Performance in Use

In addition to the earlier discussion of cellulosic fiberboard and hardboard racking and acoustical performance in walls, a number of other studies have examined the structural performance of hardboard.

Structural Sandwich Panels

In 1947 FPL built an experimental unit using structural sandwich panels (Palms and Sherwood 1979). All the original panels had paper honeycomb cores and plywood or aluminum facings. After a year three replacement panels were installed, one with 1 4-inch hardboard facings and two with 1 8-inch-thick hardboard facings. In 1955 two of the aluminum-faced panels were replaced with ones faced on one side with 1 8-inch-thick hardboard and on the other side with porcelanized steel. Replacement hardboard-faced panels were also installed in 1961 and 1962. Ten hardboard-faced panels were tested in bending after up to 30 years exposure. Stiffness showed little change while strength reduction varied considerably but was generally in the range of 25 percent.

Stressed-Skin Panels

A series of prefabricated housing wall panel tests (Luxford 1957b) indicated that walls made with 2- by 3-inch framing, gypsum interior facing, and hardboard sheathing-siding met federal housing performance standards in effect at that time. In 1962, two of the original plywood-faced stressed-skin wall panels were removed from an experimental building constructed in 1937. One of the replacement panels had hardboard faces; the other had plywood faces. Heyer (1964) reported that the hardboard- and plywood-faced panels were equal in bending stiffness.

Luxford (1936) determined bending strength of panels with wood framework and either plywood or hardboard faces. Vertical "studs" were spaced 12 inches on center. In addition, some panels had horizontal stiffeners 12 inches on center. Without stiffeners, hardboard-faced panels were about 20 percent stronger than plywood-faced panels; but plywood-faced panels were about 12 percent stiffer. Stiffeners did not affect properties of hardboard-faced panels, but increased plywood strength and stiffness. This was attributed to the nearly equal hardboard strength and stiffness along and across the panel length. The 1 4-inch-thick plywood was considerably stronger and stiffer in the length direction than in the width direction.

Roof Support Systems

Four of the W-trusses in an experimental pole building at FPL (Doyle 1969) were made with 1 4-inch-thick tempered hardboard gusset plates. Stiffness of these was essentially the same as that of trusses made with 1 2-inch-thick plywood gusset plates.

In 1968, FPL began a series of studies on hardboard as the shear web in built-up wood I-beams (McNatt 1980; McNatt and Superfesky 1983; Ramaker and Davister 1972; Superfesky and Ramaker 1976, 1978). These studies showed that structural performance of such beams could be predicted from mechanical properties of the beam components and that the beams could perform adequately under long-term interior and protected exterior environments.

Hardboard in Shipping Pallets

Kurtenacker (1975) and Stern (1979a, 1979b, 1980) conducted a series of studies to develop an effective hardboard pallet design. Results indicated that pallets with hardboard decks (fig. 18) would be especially advantageous in mechanized warehouse operations because of their low diagonal distortion tendency. Prolonged outdoor exposure is not recommended because areas damaged during forklift handling exhibited increased deterioration.

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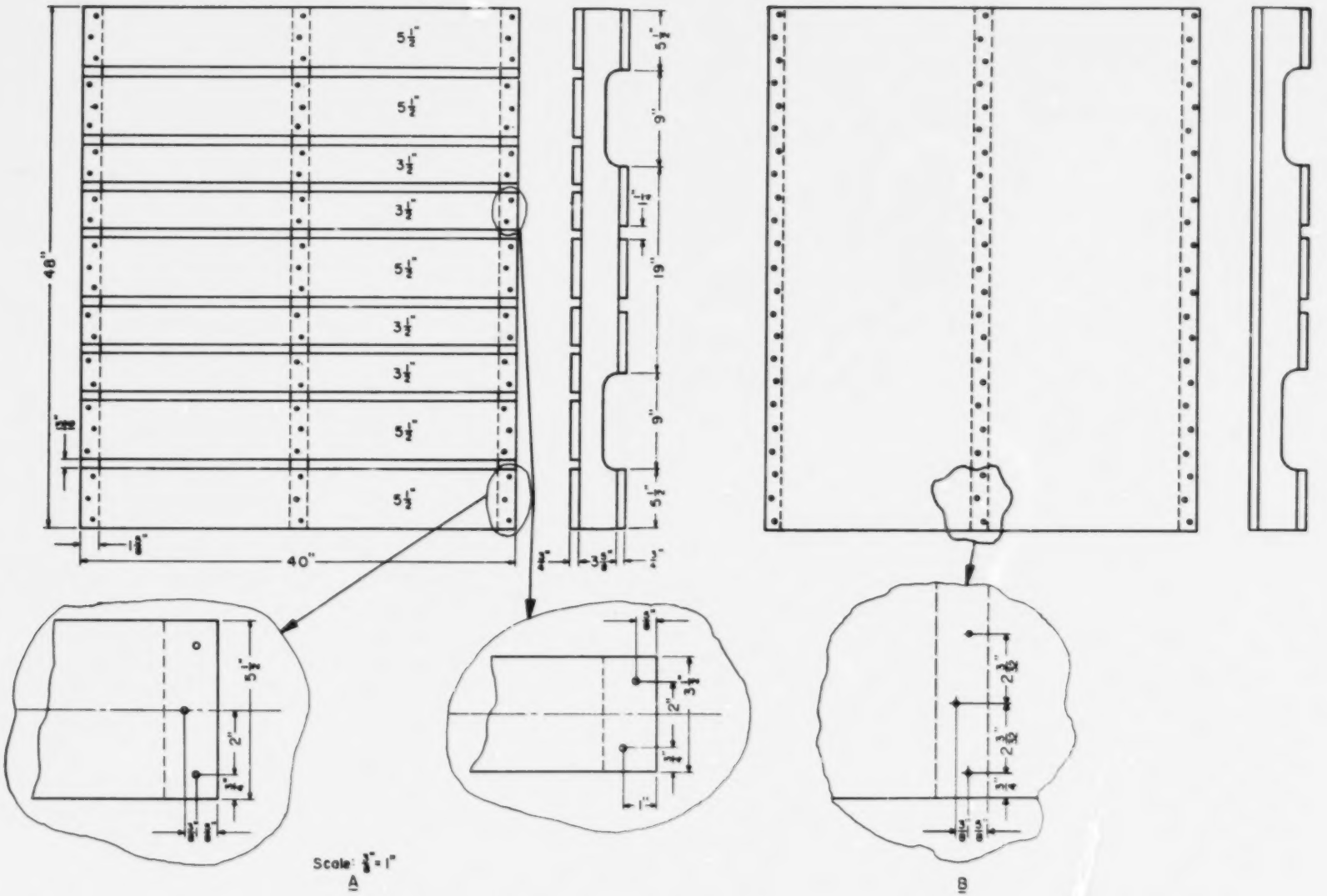

Figure 18.—Hardboard-lumber pallet designs. (A) lumber control pallet with spaced top deckboards and (B) experimental pallet with hardboard top deck. Stern 1980. (M146 547)

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Summary

For more than 50 years the U.S. Forest Products Laboratory has conducted fiberboard and hardboard research in three broad areas: processing, properties, and performance. During the 1930's and 1940's only a few studies were completed on raw material evaluations and testing. Activity in the 1950's and 1960's intensified on raw material and board property evaluations. During the 1970's and early 1980's the emphasis shifted toward processing and structural applications. Readers must be aware that this publication only covers research completed at FPL.

Most of the processing research was carried out in the areas of fiber resources, fiber preparation, fiber treatments, and additives. Many species of domestic and foreign hardwoods and softwoods were investigated. Other sources of fiber were also investigated, including residues from forests and forest products industries, clean wastepaper, fiber from municipal wastes, and fiber from agricultural residues. Fiber preparation investigated various aspects of atmospheric and pressurized refining, plus some chemical cooks. Closely aligned with fiber preparation were studies on fiber yield and characterization. Many items are added to the fibers prior to or during the forming operation, including paraffin wax, other sizing chemicals, and resins. Other fiber additives were investigated with the intention of making hardboard stronger and more stable, fire-retardant, or resistant to decay. Most of the resin additives involved different types of phenolic resins, but there was work done on some thermoplastics and resins made from renewable resources. Different resin application points were investigated.

Fewer studies were conducted on mat forming, hot pressing, and post-treatment. Aligning fibers and adding fiber glass to the fiber mats were investigated as means of increasing strength and stability. Most of the work on hot pressing involved different temperatures and pressing times. Post-treatment investigations were primarily concerned with the addition of oils or other chemicals, and/or heat-treatment, of the hardboard.

Early work in properties and performance emphasized test method development, mechanical fastener performance of cellulosic fiberboards as related to wall racking strength, use of hardboard as facings on stressed-skin and sandwich panels, and fire performance of these fiber-based panels. Later studies concentrated on basic properties of hardboard and how they were affected by loading and environmental conditions and structural use of hardboard as webs in I-beams.

Results from these studies suggest additional research possibilities. For example, the hardboard I-beam studies indicated that performance criteria such as long-term strength, resistance to creep, and response to humidity variations can be affected by processing variables (wood species, fiber refining, mat-forming, and press conditions). As more of the processing variables are studied and understood, it may be possible to manipulate the processing operation to attain a desired performance, and utilize more fiberbase panel products structurally

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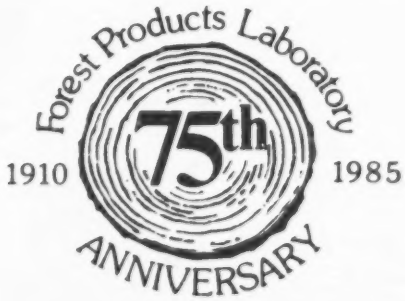
Early research at the Laboratory helped establish U.S. industries that produce pulp and paper, lumber, structural beams, plywood, particleboard and wood furniture, and other wood products. Studies now in progress provide a basis for more effective management and use of our timber resource by answering critical questions on its basic characteristics and on its conversion for use in a variety of consumer applications.

Unanswered questions remain and new ones will arise because of changes in the timber resource and increased use of wood products. As we approach the 21st Century, scientists at the Forest Products Laboratory will continue to meet the challenge posed by these questions.



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